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COAST EROSION AND PROTECTION.

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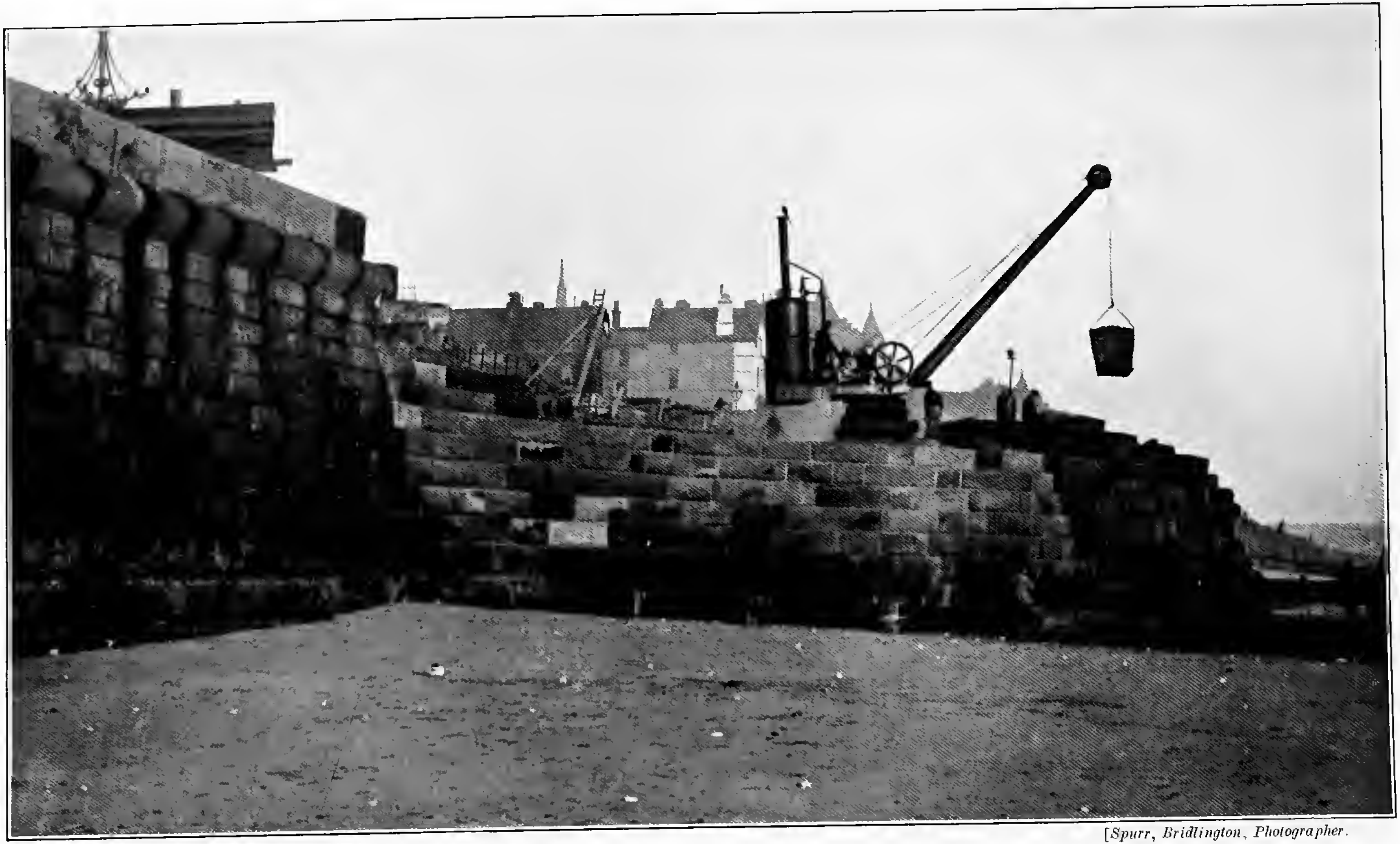

[*Spurr, Bridlington, Photographer.*

Parade Extension Sea-Wall, Bridlington.

COAST EROSION AND PROTECTION.

BY

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S

PREFACE.

THIS volume it is hoped will prove a useful contribution to the important branch of Civil Engineering known as Maritime Engineering. It gives a résumé of the erosion and accretion that is taking place around the coasts of Great Britain and Ireland, and treats comprehensively of all forms of sea-defences, the merits and demerits of each type being fully discussed. Special consideration is given to methods of construction in reinforced concrete and comparisons of costs are stated. The action of sea water on concrete is a matter of such great importance that the author has carried out numerous experiments with a view to preventing as far as possible the destruction taking place, and the results are set out herein. The action of fresh water is similarly dealt with, and careful consideration is given to the quality of materials and to preservatives against decay and corrosion. The important subject of Harbour Projections and their effect upon the travel of sand and shingle is briefly referred to.

Detailed drawings and photographs of different kinds of existing sea-walls, groynes, and breakwaters, constructed in Great Britain and on the Continent, are freely introduced as they serve to convey more clearly than description can do the nature of the work involved.

This work is based upon a series of copyright articles recently contributed by the author to *Engineering*, and also upon papers prepared by him and read before the Institution of Civil Engineers and the Society of Engineers. There is also included an article written by him for *The Surveyor* on "The Action of Sea and Fresh Water on Cement and Concrete," and other articles contributed to *The Contractors' Record* have been drawn upon. He desires to acknowledge the courtesy of the proprietors and editors for permission to make use of these articles, and also to the numerous photographers, whose names appear under the illustrations, for their kindness in granting permission to reproduce their copyright photographs of sea-defence works and wave-action on various parts of our coast.

The book sets forth the results of many years' experience in the designing and carrying out of sea-defence works, and throughout the aim has been to be practical, and details are given so as to afford a thorough understanding of the problems involved. To practising engineers and to engineering students the work is specially commended, and to all others who are interested or responsible for the protection of coast lands whether in this country or abroad.

E. R. M.

BRIDLINGTON,
June 1913.

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COAST EROSION AND PROTECTION.

CHAPTER I.

WAVE-ACTION.

(*a*) **Laws relating to Wave-Action.**—Waves are of two main classes: tidal and wind waves. It is very desirable that those designing coast protection works should have a knowledge of the laws under which waves operate. Their nature and action have been from time to time the subject of much investigation and experiment, the most important experiments carried out being undoubtedly those of the late Astronomer Royal, Sir G. B. Airy; and those of Messrs Weber, Robertson, and Scott Russell. The results of the Weber Brothers' researches were published at Leipzic in 1825; and at the meeting of the British Association at York in 1844 Mr Scott Russell reported on his researches, the title of his paper being "On Varieties, Phenomena, and Laws of Waves, and the Conditions which Effect their Genesis and Propagation." Sir G. B. Airy's experiments are set out in his treatise on *Tides and Waves.*

The experiments referred to have been carried out in various ways: the Weber Brothers, for example, used long troughs made with glass sides. They were able by the aid of these to note the surface movement of water in the trough, and also the effect of this movement at various depths below the surface; they also observed the height to which waves rose, their velocity and shape. They placed coloured particles in the water of the same specific gravity as the water, and observed the movement of these, they also watched the travel of floating objects, and by means of these simple appliances they discovered the important laws which govern wave-action. Scott Russell used similar appliances, but his troughs were much larger, and the volume of water thus dealt with was considerably greater.

The velocity and height of waves, and the laws generally which govern wave-action will not be dealt with in this volume, the subject being too comprehensive; the reader, however, is advised to consult the papers and works already referred to, and he will find much useful information on the subject in *Tides and Waves*, by W. H. Wheeler, M.Inst.C.E., *Principles and Practice of Harbour Construction*, by William Shield, F.R.S.E., and *The Design and Construction of Harbours*, by Thomas Stevenson, F.R.S.E. There are two matters, however, in connection with wave-action which are of extreme importance in designing sea-walls or breakwaters, *e.g.*—

1. The force of impact of a wave.
2. Height to which a breaking wave will rise.

These two important features will now be fully dealt with.

(*b*) **Impact of Waves.**—Some of the forces of Nature can be measured, such, for example, as the velocity of the wind, the pressure of water due to a given head, and the rate of erosion on a coast-line; but Smeaton was correct when, in referring to certain other powers of Nature, he said, "They are subject to no calculation." Thus it is that the marine engineer's task is often a difficult one. The force with which a wave strikes a plane surface, while it may be gauged approximately, cannot be accurately measured; for while a marine dynamometer will record a certain blow, this really does not represent the force of impact of the wave against, say, the upright face of the sea-wall to which the instrument is fixed, for the wall is non-elastic, while the dynamometer is usually fitted with springs or plungers, and is therefore an elastic body.

The force of impact of a wave will depend upon five things:—

1. The nature of the wave (whether a tidal or a wind wave).
2. Its length and height.
3. Its velocity.
4. The nature of the body against which the wave strikes—whether elastic or rigid.
5. The shape and position of such a body—whether it has a vertical or sloping face.

The greatest recorded force of impact of a wave was obtained at Dunbar, in the county of East Lothian, when a force of 3½ tons per sq. ft. on the surface was registered. A force of 3 tons per sq. ft. has been registered frequently. There can be no doubt that higher results than these may be obtained. The displacement of heavy bodies, and the height to which a wave rises after striking a vertical face, would indicate that the record given by the dynamometer is less than the actual force exerted. Let these two points be considered for a moment.

The Displacement of Heavy Bodies by a Wave.—This is well illustrated during every severe storm by the washing away of a portion of a sea-wall and promenade on some part of our coast, or by other damage done. During the construction by the author of the Parade Extension Works at Bridlington, for example, a number of blocks of stone, each weighing from 3 to 4 tons, were washed out of position and carried several yards away. This occurred during a severe north-westerly gale, and a view of the structure so damaged is given in fig. 1.

"At Cherbourg breakwater upwards of 200 blocks of concrete, each weighing 4 tons, were lifted by the waves during a north-easterly gale and taken over the top of the mound and deposited inside. Blocks of 12 tons were moved from their place and turned upside down."[1]

During a storm at Wick huge blocks of concrete, weighing 1350 and 2500 tons respectively, were displaced. This seems scarcely credible, and doubt has been raised as to whether this movement was due entirely to wave-action; it would seem to be within the bounds of possibility, however, when we consider that in 1894, during a storm, a large portion of the breakwater at the Bilbao harbour, estimated to weigh 1700 tons, was overturned, due entirely to wave-action. The old Beaconsfield sea-wall at Bridlington was entirely demolished by a storm, or series of storms, which occurred about eighteen years

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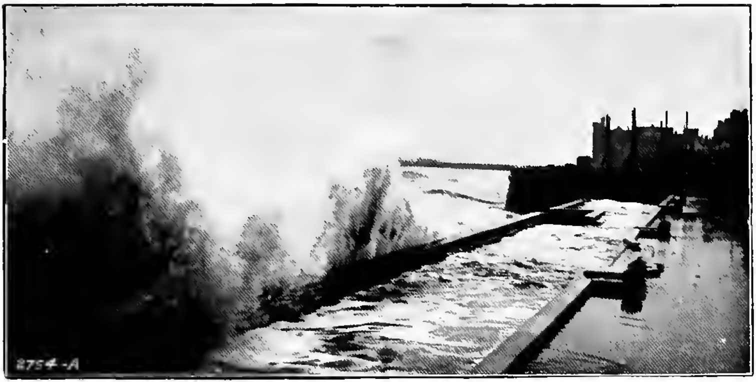
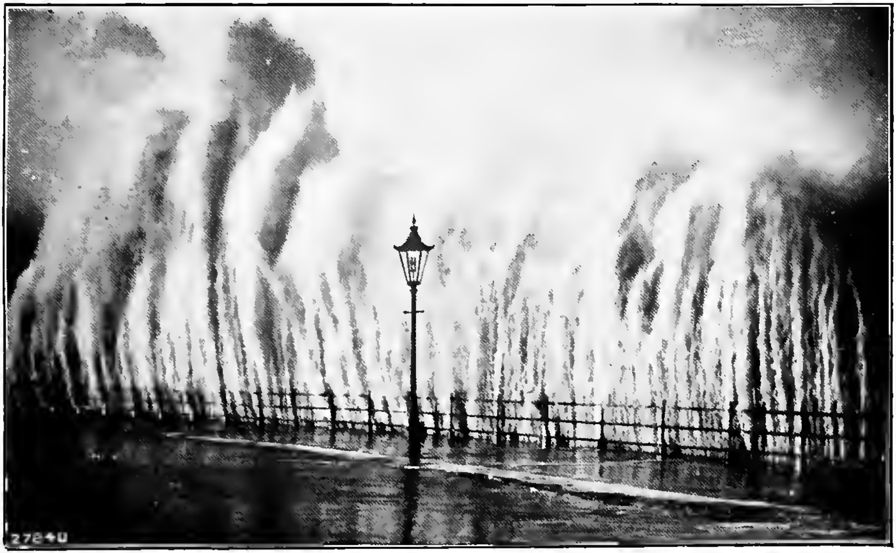
[1] *Tides and Waves*, by W. H. Wheeler, M.Inst.C.E.



[*Spurr, Bridlington, Photographer.*

FIG. 1.—NEW VICTORIA SEA-DEFENCES, BRIDLINGTON.



[*A. M. Cromack, Photographer.*

FIG. 1A.—RECORD WAVE AT SCARBOROUGH.

[*To face p.* 4.

ago, and huge pieces of the wall of concrete and brick, weighing 20 tons or more, are now to be seen upon the foreshore. During the storm which occurred in November 1911 much damage was done by the sea at Heysham, large pieces of the sea-wall being washed away.

Other examples might be given, but these will doubtless suffice to show that the force indicated by dynamometers is really less than the force actually exerted. It should also be noted that when a wave strikes a body, its action is continuous as long as the wave lasts, and not momentary, as when a solid strikes a solid. It is this continuity of impact that causes the damage.[1] Mr Thomas Stevenson puts it in a simple way when he likens it to "a continuous succession of cannon-balls falling on the body."

"The Ymuiden breakwaters (Holland)[2] are vertical, or nearly vertical structures, with mounds of concrete blocks, termed 'wave-breakers,' on the seaward side. These mounds are composed of blocks weighing from 5 to 10 tons each, thrown pell-mell into the sea. The mound has a slope of about 1½ horizontal to 1 vertical, and is surmounted by a row of 20-ton blocks. During a gale one of these 20-ton blocks was lifted by a wave to a height of 12 ft. (vertically up the face of the pier) and landed upon the top of the pier, which was 4 ft. 10 in. above high water."

The most destructive seas usually occur during an off-shore gale, a heavy ground swell is then propagated; this is illustrated in the diagram, fig. 2, and in the view fig. 3, the latter showing such a wave on the point of breaking. In this case the wind has dropped somewhat, but the ground swell remains. Fig. 4 illustrates the effect after such a wave has broken, and represents a rough sea at Bridlington; while fig. 5 shows the backwash of such a wave meeting the incoming wave. While waves usually assume their greatest force during an off-shore gale, it nevertheless is a fact that in such a gale beaches invariably heap up, while during an on-shore gale the foreshore is depleted. The author's experience, however, has taught him that serious damage to a sea-wall, or other form of sea-defence running parallel to the coast-line, seldom occurs during an on-shore gale, there is too much broken water during such a gale for much damage to be done. The type of wave propagated

---

[1] *The Design and Construction of Harbours*, by Thomas Stevenson, F.R.S.E.

[2] *Principles and Practice of Harbour Construction*, by William Shield, F.R.S.E.

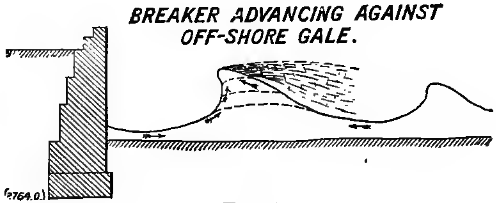


Fig. 2.

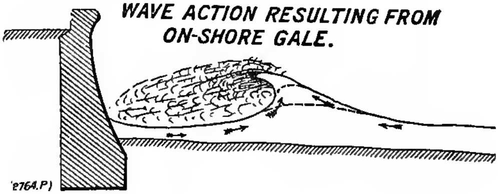
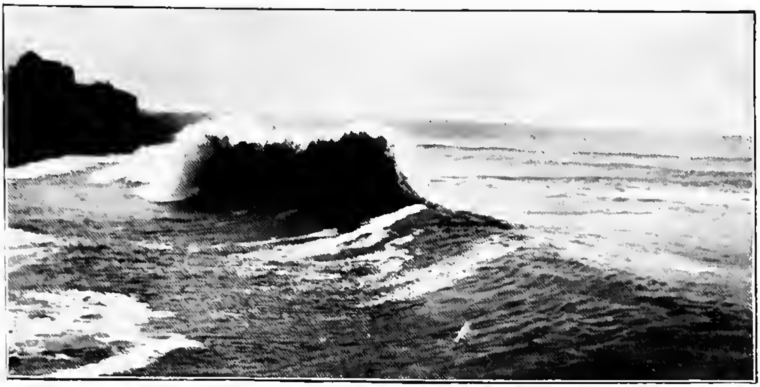
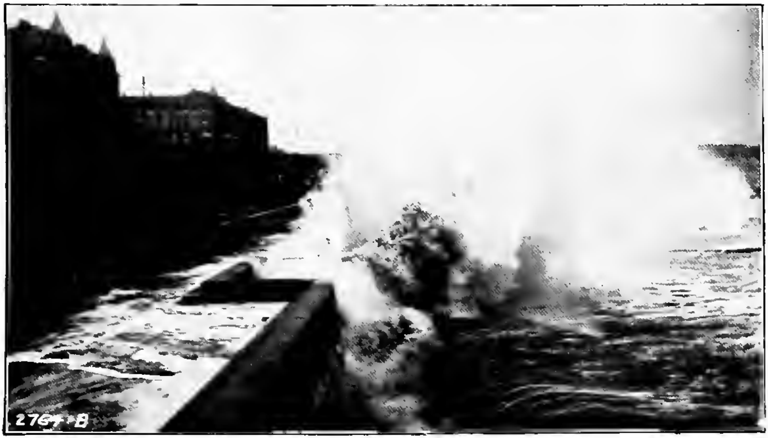


Fig. 6.



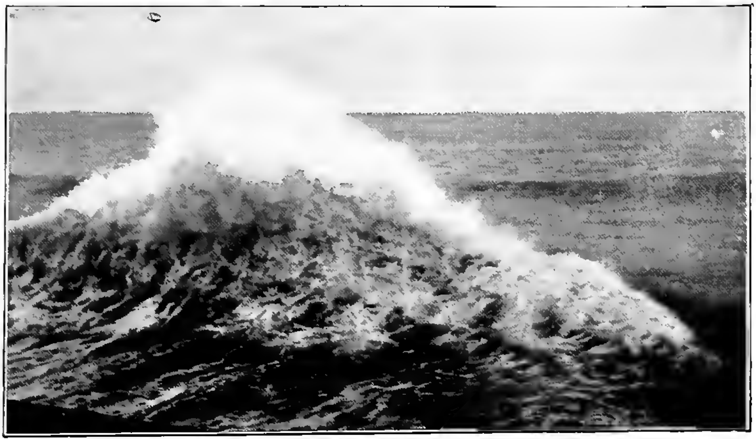
[*Spurr, Bridlington, Photographer.*

FIG. 3.—BREAKING WAVE AT BRIDLINGTON.



[*Spurr, Bridlington, Photographer.*

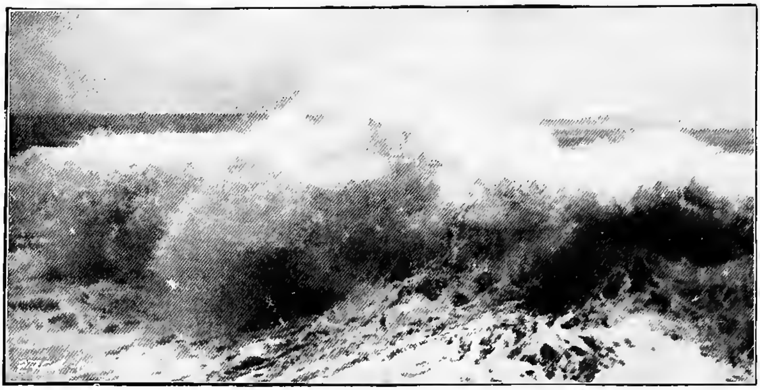
FIG. 4.—WAVE BREAKING AGAINST SEA-WALL AT BRIDLINGTON.



[*Spurr, Bridlington, Photographer.*

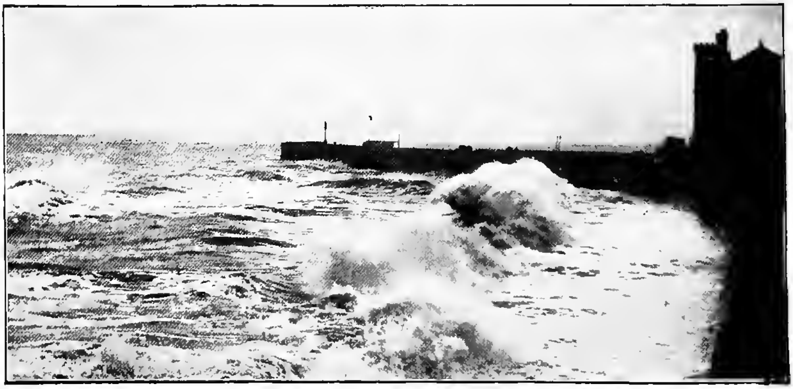
FIG. 5.—BACK-WASH MEETING INCOMING WAVE.

[*To face p.* 6.



[*Spurr, Bridlington, Photographer.*

FIG. 7.—TYPE OF WAVE FROM ON-SHORE GALE.



[*Spurr, Bridlington, Photographer.*

FIG. 8.—TYPE OF WAVE FROM ON-SHORE GALE.

at such a time is shown in the diagram, fig. 6, on page 6, and in the views, figs. 7 and 8.

The Height to which a Wave Rises after Impact.—It is quite a common thing for wave-action to take effect to a height of 30 ft. or 40 ft. above mean sea-level. In the case of a vertical cliff it would very seldom take effect at such a height, but where the face of the cliff slopes, through landslips or other causes, action does frequently take place to the height named. The author has observed that on the Holderness coast of Yorkshire, on cliffs 30 ft. to 35 ft. in height, seaweed has been washed on to the top of the cliff. In this case high-water of ordinary spring tides would be about 7 ft. above the base of the cliff. In the case of a sea-wall the wave-action is more pronounced, and where there is no projecting cornice to throw back the wave, one frequently observes that waves striking a sea-wall, which is, say, 35 ft. in height, are carried almost as high again as the height of the wall (see fig. 9) before they fall on to the promenade at the back of such wall.

A good example of this may be seen at the Marine Drive sea-wall at Scarborough. The height of this wall is about 35 ft. above the level of the foreshore, and high-water of ordinary spring tides reaches about 15 ft. up the wall. Waves striking this wall frequently rise to a height of about 30 ft. above the promenade level. The new sea-wall recently erected by the author at Bridlington, in connection with the extension of the Royal Prince's Parade, is 28 ft. in height above the level of the foreshore, and has a stepped face (stone), the depth of water at ordinary spring tides being about 10 ft.;

and one frequently observes that, in spite of the projecting cornice, a wave will occasionally rise to a height of 20 ft. above the top of the wall. In Shield's *Harbour Construction*, page 81, we read: "It is no uncommon occurrence for storm waves, striking a vertical breakwater face, to throw heavy masses of water to a height of at least 100 ft., often very much higher. Such water in its descent, on reaching the roadway of the breakwater upon which it falls, will have attained a velocity of about 80 ft. per second, or nearly double the velocity and four times the force of the water striking the face of the breakwater."[1]

Thomas Stevenson, in *The Design and Construction of Harbours*, also gives some interesting information on this subject. The force with which a wave strikes a sea-wall, and the height to which such wave rises after impact, are well illustrated in fig. 10, which represents a wave striking the Baths sea-wall at Hastings during a storm on October 22, 1911: in fig. 11, which is a view of a huge wave rising after impact with the sea-wall on the north shore at Scarborough; and fig. 1A, which shows a record wave at Scarborough. Fig. 11A represents a storm at Wick in 1912, during which a serious breach occurred in the south pier of the harbour. This gives one an idea of the tremendous force with which a wave during a storm strikes a breakwater or pier. Fig. 11B is a side view of repaired breach, taken at low-water.

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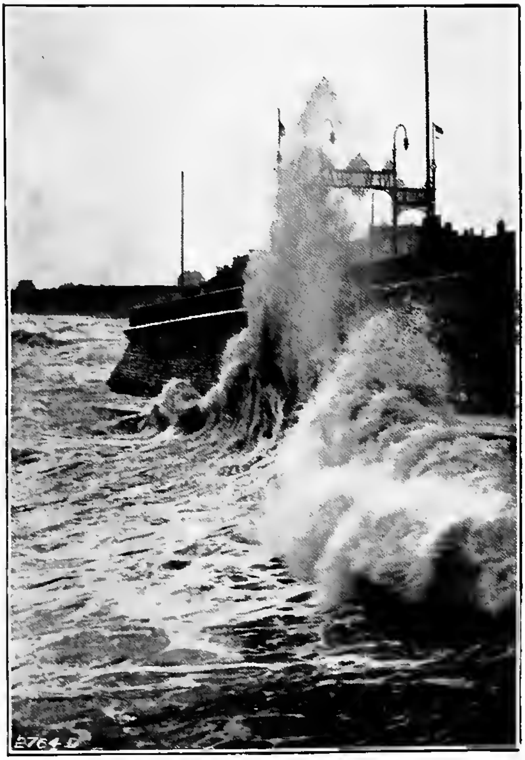
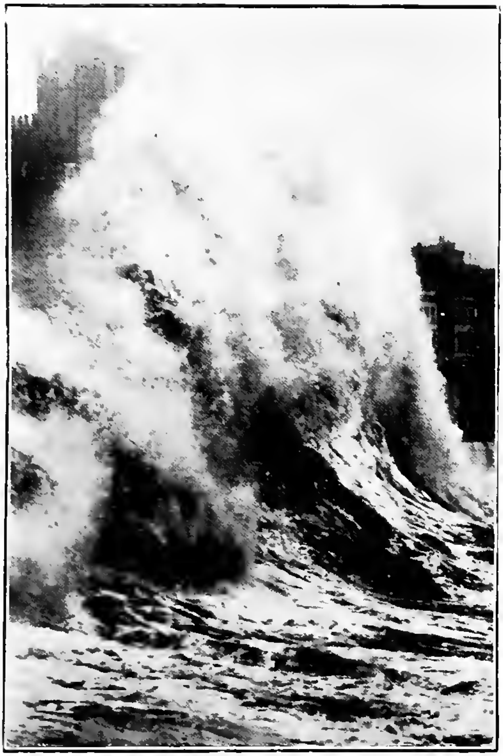
[1] *Principles and Practice of Harbour Construction*, by William Shield, F.R.S.E.



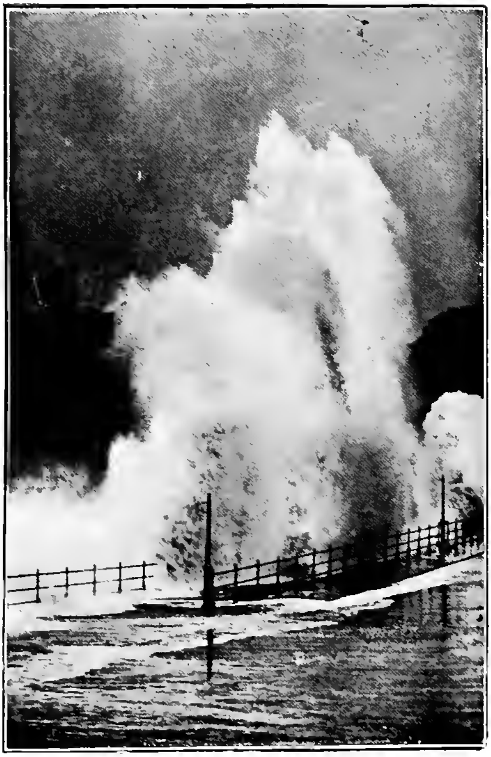
[*Spurr, Bridlington, Photographer.*

FIG. 9.—WAVE AT BRIDLINGTON.



[*Foster, Hastings, Photographer.*

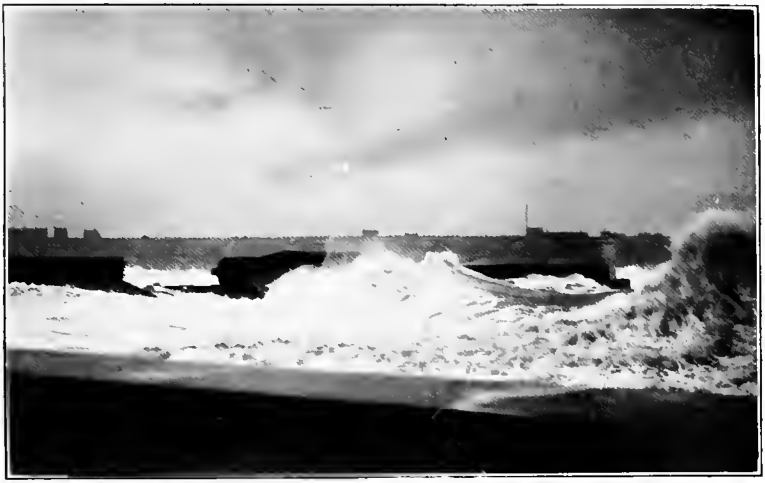
FIG. 10.—WAVE AT HASTINGS.



[*Cromack, Scarborough, Photographer.*

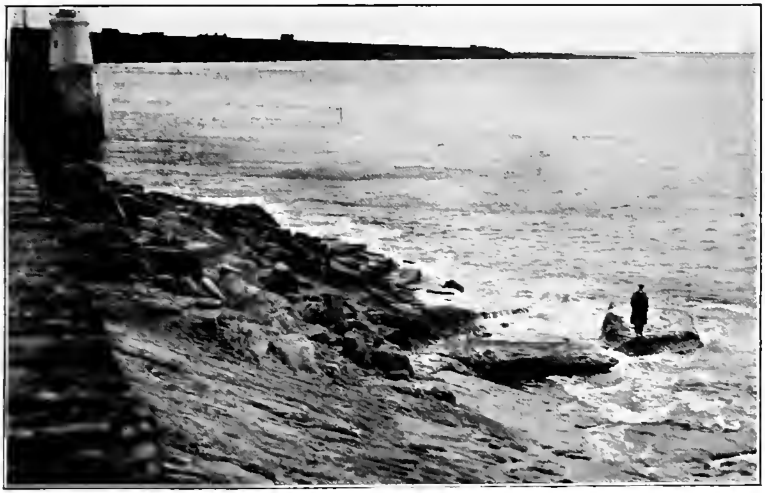
FIG. 11.—WAVE AT SCARBOROUGH.

[*To face p.* 8.



[*Johnston, Photographer, Wick and Thurso.*

FIG. 11A.—STORM AT WICK DURING WHICH BREACH IN SOUTH PIER OCCURRED.



[*Johnston, Photographer, Wick and Thurso.*

FIG. 11B.—SIDE VIEW OF REPAIRED BREACH AT LOW-WATER.

[*To face p. 8.*

CHAPTER II.

EROSION AND ACCRETION.

THE natural growth and depletion of sea-beaches is not only a subject of great interest, but is one of those larger questions which affect the nation. The configuration of the coast-line of Great Britain is not the same for two consecutive days. Headlands are growing further seawards, low coast-lines, formed of easily eroded material, are continually being set back owing to the inroads of the sea; while, on other parts of our coast, accretion is taking place very rapidly, so much so, that land is being reclaimed in large areas, and while the area of certain counties is being reduced, that of others is being steadily increased.

The principal erosion in England, as is well known, occurs on the east and south coasts, more particularly on the east coast. The reason for this is obvious. On that coast the cliffs are low and formed, for the most part, of glacial deposit, which has little cohesion, and is easily eroded. Land springs occur frequently in the boulder clay, and these increase the rate of erosion considerably. Other parts of the east coast, such as the Lincolnshire coast, consist largely of sand-dunes, which offer very little resistance to the inroads of the sea. On the south coast also, the low, flat coast-line offers very little resistance to the sea, and so we find that most of the erosion in Great Britain occurs on these two coasts—east and south.

This erosion is checked largely on those parts of the coast where the cliffs are of a more permanent character—namely, of limestone, as in Northumberland, or of chalk, as are the Dover cliffs, and Beachy Head. While chalk itself is not a very hard rock, like the rocks of Cornwall, Wales, or Scotland, still its massiveness, attaining as it does in places nearly 1000 ft. in thickness, has retarded the erosive action of the sea in some parts of both the east and south coasts. The author estimates that the rate of erosion of the chalk cliffs of Flamborough Head is about 1 ft. per annum, and this includes the occasional falling of large pieces of chalk, sometimes weighing 10 to 20 tons.

It is not necessary to deal in this article with the erosion on the west coast, except to say that it principally occurs on the Welsh seaboard. Between Llanelly and Kidwelly River, for example, an erosion of about 6 ft. per annum is going on. On the coast of North Pembrokeshire and South Cardiganshire the sea is gradually making inroads, while at Rhyl and Colwyn the erosion is somewhat alarming. North of Blackpool erosion is also occurring. At Southport and Birkdale the problem has long been not how to keep the sea from encroaching upon the land, but how to prevent it from receding farther and farther from the land. The sand-dunes of Birkdale rise to a great height above the foreshore.

A few particulars of the erosion which is taking place on the east and south coasts of England may now be given, and as the greatest erosion on the English seaboard occurs in Yorkshire, on the Holderness coast, some facts shall first be stated relative to that erosion, and also as to the deposition of the eroded material. It will be seen from these particulars how a rapid rate of erosion, with a corresponding rapid rate of accretion, sometimes occurs in a very limited length of coast-line, practically in the same locality. As to the erosion, what actually occurs is this, if the coast of Holderness be taken as an example: The boulder-clay composing the Holderness cliffs consists of clay, sand, gravel, and larger stones; the pummelling action of the wave at the base of the cliff in a short time causes huge fissures to occur in the latter, and these in time open out until a mass of the cliff falls on to the foreshore. The action of the sea on this is to disintegrate the mass, washing away the sand and fine gravel, and converting the clay into mud, which is also washed away. The larger stones and coarse gravel remain, and these are washed up to the foot of the cliff, where they are deposited, affording in a small degree a sort of natural protection to the cliff. In a paper the author read before the Institution of Civil Engineers in 1904, entitled "Erosion on the Holderness Coast of Yorkshire,"[1] a good deal of information was given regarding the rate of erosion on this particular part of our coast, and it was pointed out that this varied from 7 ft. per annum in some parts to 15 ft. per annum in other parts, the estimated average rate being 11 ft. per annum.

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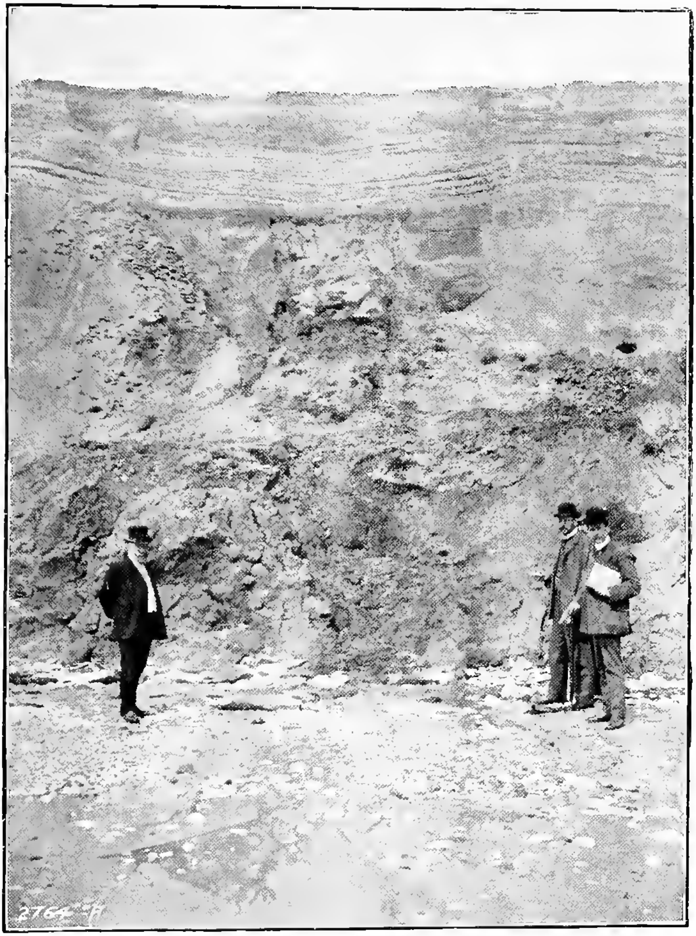
[1] *Min. Proc. Inst. C.E.* (Paper 3495), Matthews on "Erosion on the Holderness Coast of Yorkshire."

The cliffs are also being eroded immediately to the north of Bridlington—*e.g.*, the cliffs formed of glacial drift (fig. 12), which extend from the northern boundary of Bridlington to Sewerby, where the chalk cliffs of Flamborough begin (see fig. 13). The rate of erosion here is 6 ft. per annum. Landslides frequently occur: only recently 200 tons of cliff fell. The footpath on the edge of the cliff has to be set back every few months; but the chief erosion, as already stated, occurs on the Holderness coast—that is, the line of coast from Bridlington to Spurn, a distance of about 35 miles. On no other part of our coast is the rate of erosion so great. Bridlington has a sea-frontage of 2 miles (a mile north and a mile south of the harbour), and this is well protected by massive sea-walls and other forms of sea-defences, which will be described in a later chapter.

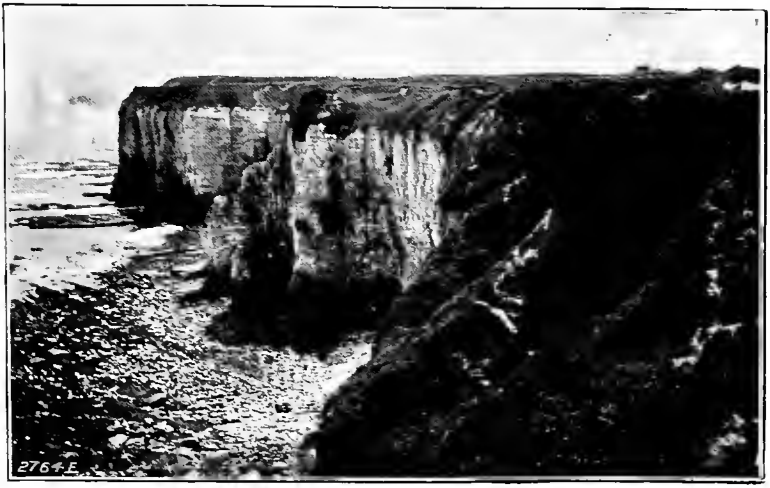
At Hornsea and Withernsea two substantial sea defences have been carried out, and the erosion stopped. Except, however, for the sea-frontage of these towns, the Holderness coast is quite unprotected; the erosion is therefore alarming. On this coast several ancient towns and villages have been swallowed up by the sea. Proceeding south from Bridlington, the first village arrived at is Wilsthorpe. This small township has long ago been washed away, and the only remaining cottage in the parish (see fig. 14) had to be pulled down in 1905, in order to save the materials. Ten years before, it had between the house and the edge of the cliff a long garden, a grass paddock, and a public footpath, and previous to this a public highway. Auburn is next met with as we proceed south; the site of the ancient village of that



[*Spurr, Bridlington, Photographer.*

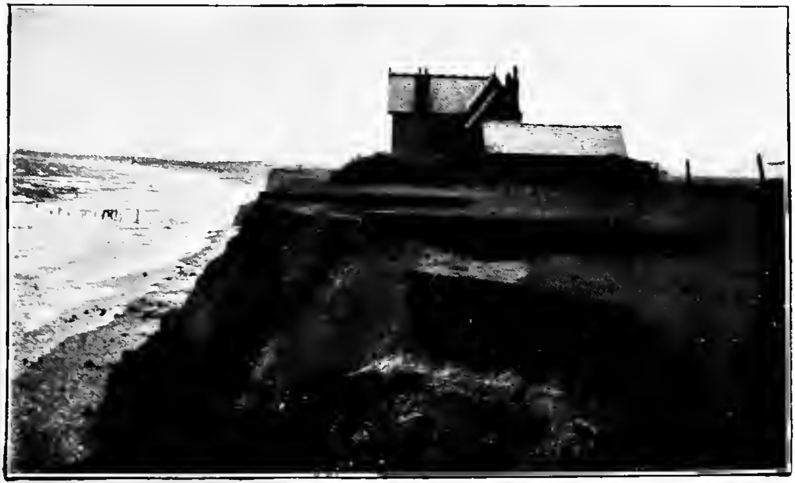
FIG. 12.—CLIFFS IMMEDIATELY TO THE NORTH OF BRIDLINGTON.

[*To face p.* 12.



[*Spurr, Bridlington, Photographer.*

FIG. 13.—FLAMBOROUGH CHALK CLIFFS.

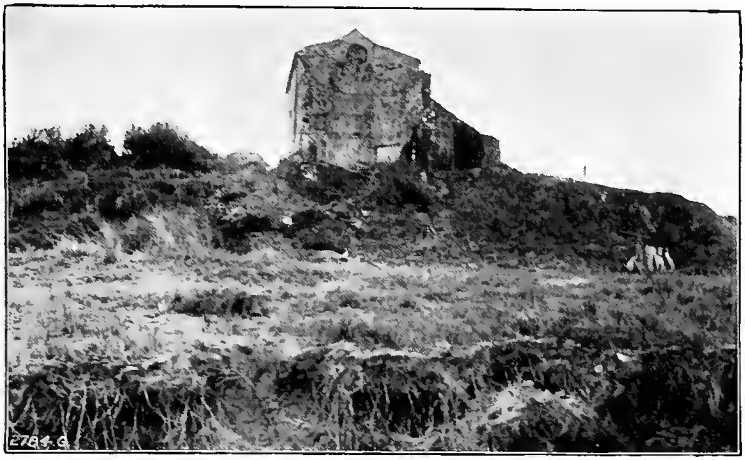


[*Spurr, Bridlington, Photographer.*

FIG. 14.—GENERAL VIEW OF HOLDERNESS COAST SHOWING EROSION.

[*To face p.* 12.

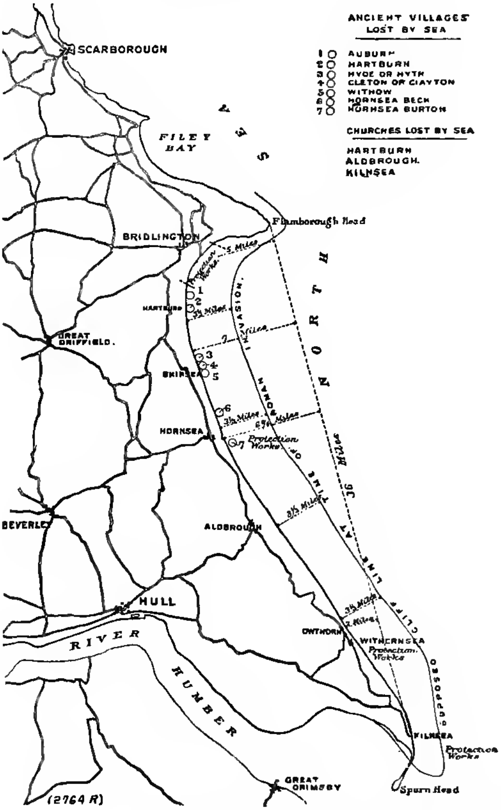
name is now far out to sea, and at high-water of spring tides is covered by nearly three fathoms of water. Only two houses of this village now remain, and one of these, which at one time stood back some distance from the cliff, now projects partly over the latter ; in fact, part of it has already tumbled over (see fig. 15). Immediately to the south of Auburn the village of Hartburn once stood, but this has gone in a similar manner, no trace of it remaining. Barmston comes next.



[*Spurr, Bridlington, Photographer.*

FIG. 15.—HOUSE PARTLY FALLEN OVER CLIFF NEAR BRIDLINGTON.

The travel of material along this coast is from north to south. The beach is fairly level, having a gradient of about 1 in 60. Spring tides range about 16 ft., and the depth of water at the foot of the cliffs at high-water of ordinary spring tides is about 3 ft. Low-water of ordinary spring tides reaches a point about 160 yards (average) from the cliffs. The author visited Withernsea on February 24 last, and observed that a farmhouse on the cliff just to the north of that town was partly undermined by the action of the sea. Ten years ago a field and a road divided this farmhouse from the cliff, but these have both disappeared. Between Kilnsea and Spurn Point there are a series of sand-hills, for the boulder-clay here sinks low. These sand-hills present a very barren appearance. Practically the whole of the village of Kilnsea has been swallowed up during the past century.



(Reproduced by permission of the Institution of Civil Engineers.)

FIG. 16.—MAP SHOWING EXTENT OF EROSION ON HOLDERNESS COAST.

In giving evidence before the Royal Commission on

Coast Erosion, and in the paper before-named, the author gave some calculations which he had made as to the extent of the erosion of this coast from the earliest times. He estimated that over 1,900,000 tons of cliff were washed away annually. The erosion has been estimated by some engineers to be 3,000,000 tons per annum. Also that 3,052,000,000 tons of cliff had been swallowed up during the past century, based on an annual erosion (average) of 3 yards. As to the area lost, taking 1 acre per mile of coast-line as the area annually washed away, and assuming that this has been going on since the Roman Invasion under Julius Cæsar, no less than 66,600 acres have disappeared during that time. The present rate of erosion on the Holderness coast is 11 ft. per annum ; but suppose it is taken as 9 ft. only, and assume that this loss has been continuous since the Roman Invasion, 55 B.C., then the sea has made an inroad to the extent of 3⅓ miles, as indicated in fig. 16 on opposite page.

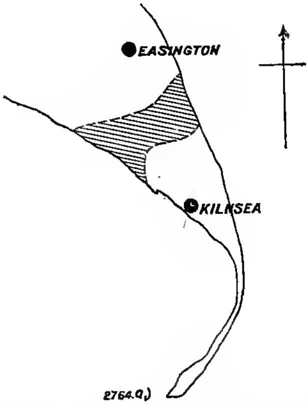
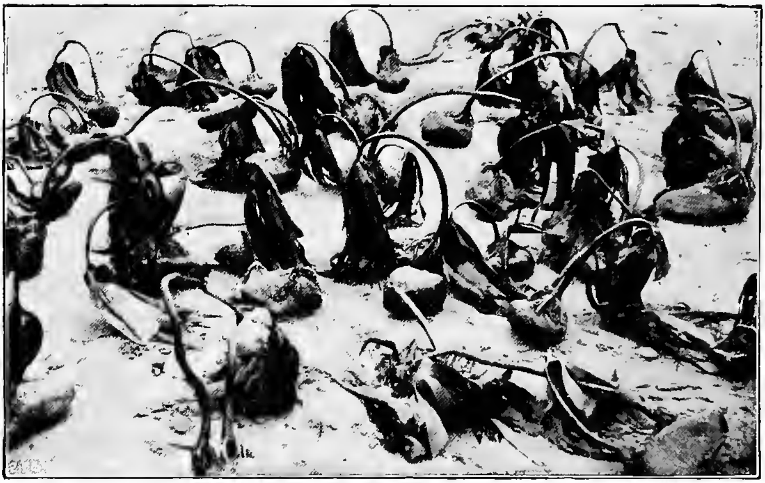


FIG. 17.—HOLDERNESS COAST, SHOWING WHERE SEA IS LIKELY TO BREAK THROUGH.

Erosion of the Bed of the Sea.—Opinions differ regarding the extent of the erosion of the bed of the sea. That erosion is taking place there can be no doubt, and this is caused by one or more of the following :—

1. The action of waves.
2. Tidal or other currents.
3. Submarine fresh-water springs (such as the Bridlington intermittent springs—so common where glacial drift lies above the chalk).



[*Spurr, Bridlington, Photographer.*

FIG. 18.—SEAWEED ATTACHMENTS TO STONES.

A clear evidence of deep-sea erosion may be seen on any foreshore after a severe storm. Fig. 18, is a photograph taken on January 22, 1912, on the foreshore at Bridlington, and illustrates a number of large stones with lengthy seaweed attachments. These stones were torn up from the rocky bed of the ocean, probably a mile or more from the shore. The photograph was taken after severe south-easterly and easterly gales.

The question necessarily arises, Can deep-sea erosion be prevented ? And one is bound to reply in the negative. Coast erosion can be, but deep-sea erosion cannot.

Deposition of Eroded Material.—What becomes of the eroded material from, say, the Holderness coast ? This is the question which one naturally asks. In what direction has it gone, and where has it ultimately been deposited ? Let us consider these questions for one moment. First, as to the direction ; it has undoubtedly travelled south, for the travel of material on this coast, as we stated in Chapter I., is from north to south. A large portion has been deposited at Spurn, for we find that here vast quantities of sand and shingle are gradually accumulating. The sea between Flamborough and Spurn during a storm is thick with suspended matter from the Holderness coast, and the author has observed the sand level at Bridlington (prior to the erection by him of a system of groynes) lowered during a severe gale 3 ft. The eroded material is, in the author's opinion :—

(*a*) Partly deposited at Spurn, and accounts for the rapid growth of that headland.

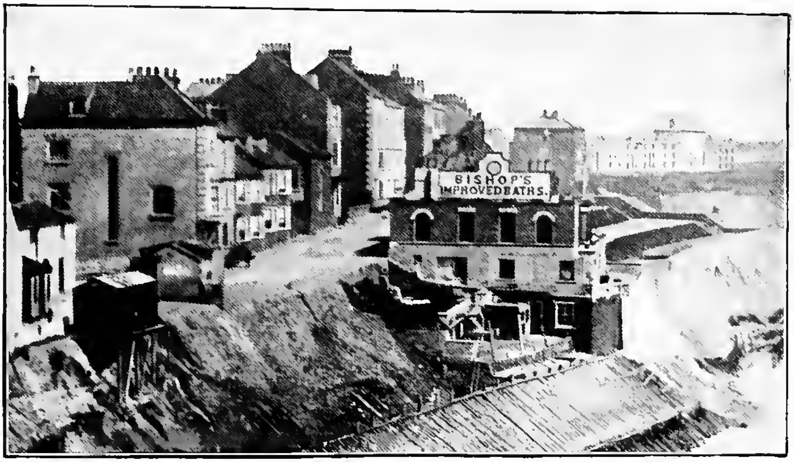
(*b*) Part enters the estuary of the Humber, and accounts for the large accumulations there.

(*c*) Part crosses the Humber, and accumulates on the Lincolnshire coast.

Threatened Spurn.—The sketch, fig. 17, on page 15, indicates the point where the North Sea last broke through into the estuary of the Humber, and it is at this point, in the author's opinion, that unless substantial sea-defences are erected, there will be formed a permanent connection between the North Sea and the estuary, Spurn, with Kilnsea, being cut off from the mainland. There is really nothing to prevent this, as the coast-line is very flat, and consists of movable sand and shingle, the boulder-clay forming the cliffs to the north of this point dipping below the shore level before it reaches Easington. That a permanent connection at this point with the North Sea would be most detrimental to the estuary of the Humber scarcely need be stated, as the eroded material from the Holderness coast, or at any rate a large portion of it, would be carried through this channel, and would have to be removed by the Humber Conservancy Board. The cost of dredging would be enormous; not only so, but the tidal currents in the estuary would be affected, and this might be serious as regards shipping.

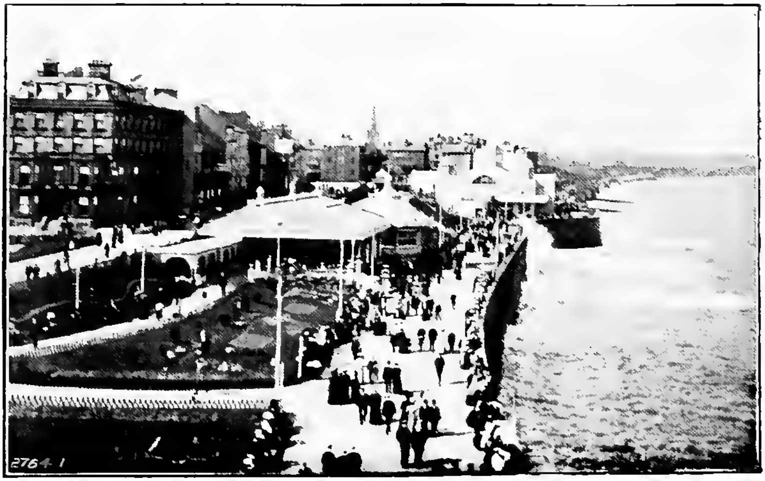
Bridlington Sea-Defences.—The Bridlington Corporation and private landowners at Bridlington have spent over £100,000 in protecting the town against the inroads of the sea, and this is a serious matter, seeing that it represents the rateable value of the borough. Fig. 19 represents the north foreshore as it was forty-five years ago, while figs. 20, 21, and 21A show the substantial manner in which it is protected to-day. At Filey a 1s. 1½d. rate has to be levied to meet the interest and repayment of the loan for coast protection works.

The Holderness coast is certainly one of the most interesting parts of our coast, for towns and villages which were once in a flourishing condition, and were situated on this coast-line, have long since been swallowed up by the sea. A few particulars of these were given by the author in an article which appeared in *The Contractors' Record*, dated June 16, 1909. The reader interested in



[*Spurr, Bridlington, Photographer.*

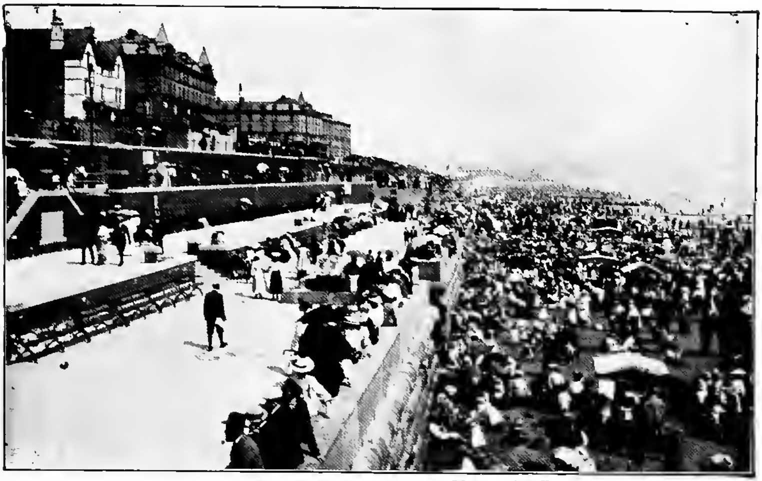
FIG. 19.—ORIGINAL SITE OF PRESENT ROYAL PRINCE'S PARADE, BRIDLINGTON.



[*Spurr, Bridlington, Photographer.*

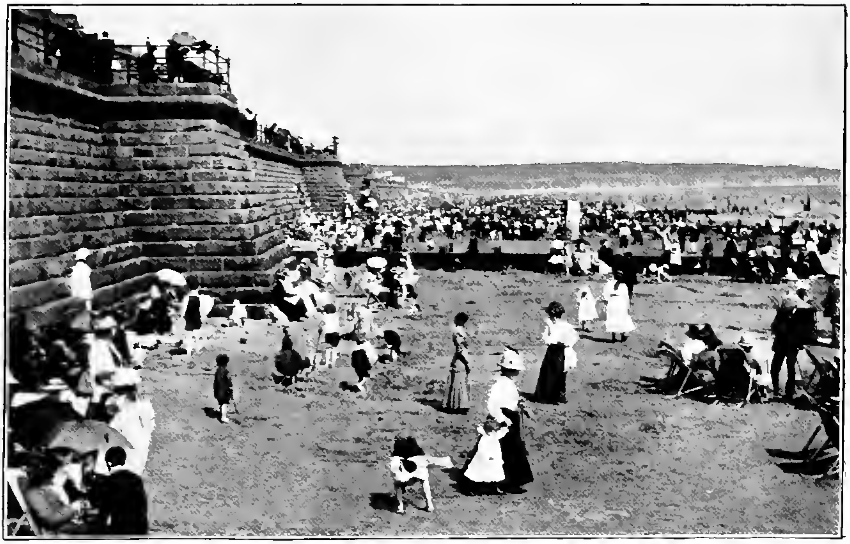
FIG. 20.—ROYAL PRINCE'S PARADE, BRIDLINGTON, SHOWING RECENT EXTENSION.

[*To face p.* 18.



[*Spurr, Bridlington. Photographer.*

FIG. 21.—NEW VICTORIA SEA-DEFENCES, BRIDLINGTON.



[*Spurr, Bridlington, Photographer.*

FIG. 21A.—BEACONSFIELD SEA-WALL, BRIDLINGTON.

the records of long-lost towns and villages is referred to that article. Here only a few facts can be briefly stated.

One of the chief of these lost towns is undoubtedly Ravenspur, situated at the mouth of the Humber, in the immediate vicinity of Spurn Point. It is the opinion of the author that the town was finally engulfed about 1500. The town of Ravensrod, sometimes referred to as Ravensrodd, was a neighbouring town to Ravenspur. It was situated a little nearer to Spurn Point, and was of less importance than the latter town. It was engulfed by the sea in 1396.

And now as to the lost towns and villages on the Holderness coast. On a map dated 1786, prepared by John Tuke, county surveyor, the following places are indicated as having been submerged :—Hornsea Burton, Hornsea Beck, Hartburn, " washed away by the sea " ; Ancient Withernsea, Hyde, or Hythe, " lost by the sea " ; Ancient Aldborough, Friesmarsh. To these might have been added Owthorpe, Old Kilnsea, and one or two other small towns. At Old Kilnsea the fine old Norman church lasted well into the nineteenth century. The present Kilnsea is a small village over a mile from the site of the ancient town.

Coast-Line, Berwick to Flamborough Head.—The sea is making very little inroad north of Flamborough Head ; that is, with the exception, perhaps, of half-a-dozen short stretches of coast. From Berwick-on-Tweed to Sunderland the coast has remained practically unchanged for centuries. Between Berwick and the Snook sand-dunes occur ; but speaking generally, the coast from Berwick to Flamborough Head is protected by rocky cliffs. There are, however, certain short lengths of this coast-line that are not protected by cliffs of so permanent a character where the sea is making inroads. On the Durham coast, for example, a good deal of erosion is going on, but fortunately this extends for only a very short distance. At Whitby considerable erosion is occurring, and the cliffs at Robin Hood's Bay are being eroded; while at West Hartlepool are to be found upon the foreshore the remains of a submerged forest. At Filey the cliffs are rapidly vanishing, landslips of considerable magnitude frequently occurring. This erosion is taking place between Filey Brig and the chalk cliffs of Speeton.

Humber to Thames.—Proceeding southwards from the Humber we find considerable accretion is taking place on some parts of the Lincolnshire coast. This is due undoubtedly to the eroded material from the Holderness coast travelling southwards around Spurn Point, across the estuary of the Humber, and becoming deposited on the Lincolnshire coast; in fact, the accretion which is taking place there cannot be attributed to any other main cause. Proceeding still further south on the same coast, we find that considerable erosion has occurred at Mablethorpe and Skegness, the old town of Skegness having been washed away, including its castle, strong fortifications, and church. It would appear, however, that the inroads of the sea are now abating at Skegness, and occurring about four miles further north; in fact, some of the portions of the new town are now being built on reclaimed land. In the estuary of the Wash huge tracts of land have been reclaimed from time to time. From the Wash to the Thames (Norfolk and Suffolk coasts) the coast-line consists for the most part of glacial drift and boulder clay, with here and there sand-dunes or wide alluvial deposits, and flat sandy banks. The sea here is very shallow for many miles from the shore. It is needless to say that considerable erosion is taking place on these coasts. At Sheringham, for example, the average rate of erosion for the past one hundred years is said to have been 2 ft. per annum. At Southwold it has been a more serious matter, for the advance of the sea upon the land here has been at the rate of from 5 to 15 yards per annum. Mr J. B. Redman has stated that the erosion between Cromer and Mundesley has been at the rate of 14 ft. per annum, and it is estimated that at Cromer the sea has encroached 2 miles since Roman times.

The inroads of the sea on the Norfolk coast can be best realised when one stands on the cliffs which stretch from Sheringham to Happisburgh. It is possible to see at Cromer, at low-water of spring tides, a clump of rocks known as the "Church Rock." These mark the site of a once flourishing town called Skipden. The cliff between Cromer and Mundesley receded 330 ft. between 1838 and 1861, showing an annual loss of 14 ft. From 1861 to 1905 the loss was 840 ft., or at the rate (average) of 19 ft. per annum. Other villages which have disappeared from the Norfolk coast include Whimpwell, Overstrand, and Eccles. At Sidestrand the ruined church is now on the edge of the cliff, and in a year or two it, together with the churchyard, will have been washed away. Where there is a particularly weak place in the cliff-line the sea naturally first attacks this, and makes an inroad. Horsey

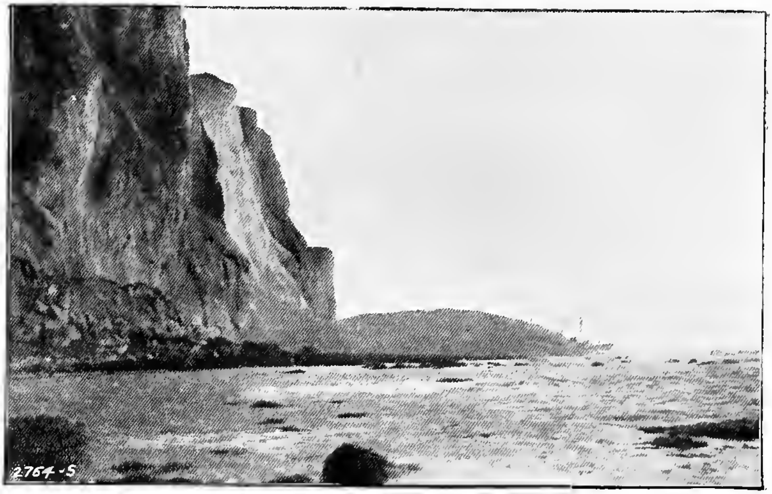
Gap is one of these weak places, and is now historical, for John Oxnead records that in December 1287 an inundation occurred here, causing vast devastation and loss of life.

Little erosion is occurring on the 6 miles of coast-line included within the County Borough of Great Yarmouth. About three years ago the Corporation had some trouble with about 400 yards of beach south of the Wellington Pier, where two short wood groynes had been put in previously. These were much in the way, and so the borough engineer, Mr Cockrill, put in two concrete groynes, finishing the surface slightly above beach level; these are now covered, and, with the exception of a few days after an easterly wind, there is no scour. The sea front at Great Yarmouth is protected by three piers in the centre of the town, and also by the works at the harbour. In the last fifty years accretion has taken place very considerably, so that the town may be said to have extended seawards during that time an average of 300 ft. along the entire sea-front. At Gorleston, owing to pier extensions at the river's mouth, considerable scour took place south of the harbour; this was stopped by the Commissioners constructing a spur breakwater. Gardens at Great Yarmouth have been laid out on what was previously dirty beach, which, being above high-water mark, was never covered by the sea. From Lowestoft to Pakefield, the loss of cliff is estimated by Mr W. H. Wheeler, M.Inst.C.E., to be at the rate of 11 ft. per annum. The whole of the Suffolk coast, however, is not suffering from the inroads of the sea. There are short lengths of this coast-line, particularly in the north of Suffolk, where much accretion is taking place. From Aldeburgh to Bawdsey, for example, there is one of the finest spreads of shingle on the foreshore which it is possible to find on any part of our coasts, and this undoubtedly has acted as a natural protection to that part of the coast-line.

CHAPTER III.

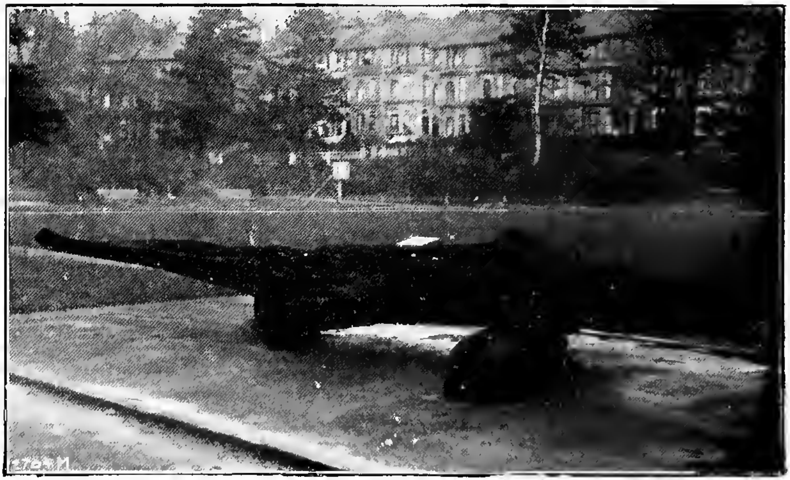
EROSION AND ACCRETION—(*continued*).

Coast South of the Thames.—A good deal of erosion is occurring immediately south of the Thames, from Sheerness to Ramsgate. Between 1872 and 1896 the encroachment at Herne Bay amounted to from 1000 ft. to 1300 ft. Landslips also frequently occur on this part of the coast. At Herne Bay the cliffs are of clay, and the burden upon the rates owing to the cost of foreshore protection is almost more than the town can bear. In the time of Henry VIII. Reculvers was a mile from the sea, and Leland, writing in 1530–37, says the village of Reculvers stood within a quarter of a mile of the seaside. In 1809 the church had to be pulled down owing to the inroad of the sea. A few years afterwards the remainder of the village was washed away, excepting two towers, which have been preserved, and have been well protected by the construction of sea-walls. The chalk cliffs of Kent have also suffered very severely, the face of the cliff being steadily driven back, and huge landslips occasionally occur. Abbottscliffe, between Dover and Folkestone, was, on January 1, 1912, the scene of the most extensive fall of cliff which has taken place on that part of the coast for many years, the amount of the slide being computed at some hun-



[*Whorwell, Dover, Photographer.*

FIG. 22.—THE FALLEN CLIFF NEAR DOVER.



[*Breech, Hastings, Photographer.*

FIG. 23.—TREE IN ALEXANDRA PARK, HASTINGS.

dreds of thousands of tons (see fig. 22). The chalk extended like a causeway some 400 yards to sea. It was about 200 yards wide and at some places 30 feet deep.

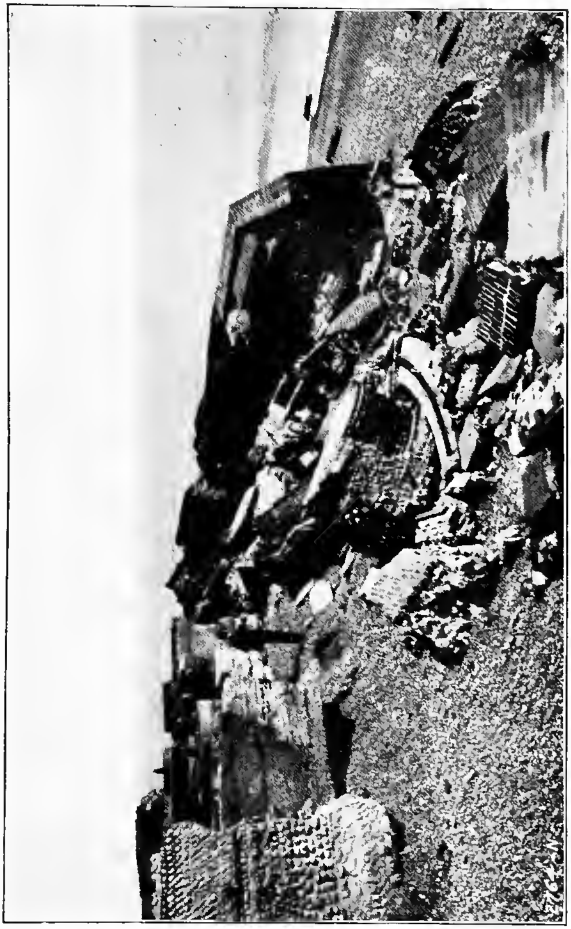
Erosion and Accretion on South Coast.—A great deal of the eroded material from the south-east coast has found its way in a southerly direction to Dungeness, and accounts for the rapid growth of this headland. Between 1689 and 1844, we are informed by Mr J. B. Redman, the rate of the extension seaward of this headland was 7 yards per annum. The Trinity House records show its rate of advance to have been 9 ft. per annum between 1792 and 1850; between 1850 and 1871 it was from 13 ft. to 14 ft. per annum; and between 1871 and 1897, 8 ft. per annum is recorded. It is interesting to note that the lighthouse here has had to be shifted three times during the past century. The foreshore at the point is very steep, so that 100 yards from the shore at low-water there are 4 fathoms of water, and 330 yards from the shore at low-water there are 15 fathoms of water.

Proceeding along the south coast, the first place to be met with where erosion to a serious extent is taking place is at Bexhill, and on the coast-line generally from thence to Eastbourne. Hastings is so well protected by substantial sea-walls that the sea has not been able to encroach upon the land; the foreshore, however, in front of these sea-walls has during the past twenty years considerably changed its appearance, for while in some parts large banks of shingle protected the sea-wall, now this natural embankment has been washed away, and the bedrock is visible on certain parts of the foreshore. This occurs chiefly on the leeward side of the old high timber groynes, which type of groyne we shall refer to later.

The erection a few years ago of the harbour at Hastings has been blamed for this depletion of the foreshore, but it is the author's opinion that this structure has in no way affected the sea-front immediately in front of the town, for the general travel of shingle on this coast is from west to east—that is, towards Dungeness Point, where it meets the travelling material from the East Coast coming in a southerly direction. In the Alexandra Park at Hastings may be seen the remains of a tree which at one time grew near the seaward end of the present Hastings Pier (see fig. 23). The excellent sea-walls and concrete-block groynes constructed at Hastings by the author's former chief—Mr P. H. Palmer, M.Inst.C.E.—cannot be spoken of too highly. Some of these interesting structures will be described later.

At Bexhill the sea has, during the past few years, done considerable damage. In 1906 a roadway near Cooden Golf Links, about 2 miles west of Bexhill, was washed away, and there is no part of the south coast which is being more rapidly eroded at the present time than that portion from Bexhill past Pevensey Sluice and Langley to Eastbourne.

At Langley Fort, near Eastbourne, the sea has done considerable damage, and made great inroads during the past ten years (see fig. 24). The sea is having the same scouring effect upon parts of the foreshore at Eastbourne as is taking place on some parts of the foreshore at Hastings, and which has already been described. Proceeding still further along the south coast, we find that erosion is



[*Lavis, Eastbourne, Photographer.*

FIG. 24.—ACTION OF THE SEA ON LANGLEY FORT, NEAR EASTBOURNE.

going on between Newhaven and Brighton, the loss of land immediately to the east of Brighton being considerable. Serious encroachments are also occurring from Shoreham to Chichester Harbour. Rapid erosion is taking place at Selsey. It was here that the cathedral of this district stood before Chichester was founded, but this building has long been washed away, and it will be remembered that in December 1910, during a severe storm, the sea broke through this headland and converted it into an island. On the Isle of Wight, at Freshwater, and near Bembridge, the sea is steadily advancing on the land; a large portion of the cliff near the Freshwater Redoubt has recently fallen into the sea, and the footpath leading up to the beacon erected to the memory of Tennyson has also been carried away. The coast-line near Torquay and at Swanage and the strip of coast near Sidmouth record the same. At Mount's Bay, in Cornwall, may be seen upon the foreshore the remains of a submerged forest.

Eroded Material: where Deposited?—The question must necessarily be asked, What becomes of this eroded material, and does the gain correspond with the loss? The author has endeavoured to show what has become of the eroded cliffs of the Holderness coast, and a similar process is going on all around our coasts. Dungeness headland is a striking example of the arrest of eroded material travelling in one direction, in this case from north to south, by other material travelling in another direction—namely, from west to east. Taking the country generally, it may be claimed that the gain equals the loss, but the author strongly disputes this statement, for much of the eroded material settles upon the bed of the ocean, and is not deposited again on other parts of the coast. Even if it were, it is of little gratification to a landowner or a corporation to know that his or their land has made its appearance on some remote part of the coast; and it is adding insult to injury when the Crown, which has hitherto contributed nothing to the cost of protecting the coast, promptly seizes the new land when it appears. This is continually happening on the Yorkshire coast, the case of the growth and reclamation of Spurn and Sunk Island being striking examples. Particulars of the growth of Spurn may here be given. At one time this was an island, and its connection to the mainland was a more or less gradual process. In 1660 the high-water mark extended just to the south of Kilnsea, Spurn being simply a heap of shingle some distance to the south. Collins, in his chart, dated 1684, shows Spurn connected to the mainland; but it is difficult to say whether this was correct, as later surveys show Spurn to be still an island. From 1820 to 1852 it was only an island at high-water. In 1852, however, high-water spring tides only submerged two places. In December 1849, during a N.N.W. gale, a serious breach was made in this niche of land, about half a mile to the north of the then high lighthouse. It was 320 yards wide, and at high-water of ordinary spring tides it had 12 ft. of water in it. It was subsequently made good by the deposit of chalk. Since 1852 Spurn has been well protected by groynes, and it is gradually extending to the south and west. Mr A. E. Butterfield, the engineer to the Humber Conservancy Board, stated in a paper entitled "Notes on the Growth of Spurn," read before the Yorkshire Naturalists' Union, in July 1904, "that the westerly movement of Spurn between 1851 and 1888 had been at the rate of 8 ft. per annum on the east, or North Sea side, and 17 ft. per annum on the west, or Humber side, showing that the point had increased considerably in width."

As to the growth of Sunk Island. In 1660 this island consisted merely of two huge sandbanks; in 1850, 7000 acres had been warped; since then many thousands more.

CAUSES OF EROSION OTHER THAN THE SEA.

1. **Removal of Material from the Foreshore.**—Another fertile cause of coast erosion besides the action of the waves is the removal of shingle from the beach by builders or landowners for building purposes, and often its removal by local authorities for road-making purposes. It sometimes even happens that the War Office and the Admiralty are offenders in this respect.

2. **Drainage.**—Land drains often hasten the rate of erosion; particularly is this so on the Holderness coast, where the drains in many cases discharge on the face of the cliff, and loosen the clay and gravel composing the cliff, making it more easily washed away by the incoming tide. The sea obtains an inroad first at these places, the result being that in South Holderness the cliffs present a saw-tooth shape on a huge scale.

3. **Land Springs.**—These have already been referred to; they assist the rate of erosion considerably.

4. **Variation in Coast-Defence Works on the same Coast.**—One of the most serious matters in the protection of a coast-line is the fact that badly-designed protection

works on one part of a coast will injuriously affect another part of the same coast. The author must not be understood to suggest that there should be uniformity of design in all sea-defence works; far from it. What would be most suitable and extremely effective on one part of a coast may be of little use on another part; but the central authority who are to deal with the protection of our coasts will have an important duty to discharge in seeing that the protection works of one locality are not of such a nature as to be injurious to the neighbouring authority or landowner.

Report of Royal Commission.—The Royal Commission on Coast Erosion, appointed in July 1906, after taking an immense amount of evidence on this important matter, and visiting many parts of our coasts and the coasts of Holland and Belgium, issued in May 1911 their third and final report. The terms of reference were as follows:—

To enquire and report—

(*a*) As to the encroachments of the sea on various parts of the coast of the United Kingdom, and the damage which has been, or is likely to be, caused thereby; and what measures are desirable for the prevention of such damage.

(*b*) Whether any further powers should be conferred upon local authorities and owners of property with a view to the adoption of effective and systematic schemes for the protection of the coast and the banks of tidal rivers.

(*c*) Whether any alteration of the law is desirable as regards the management and control of the foreshore.

(*d*) Whether further facilities should be given for the reclamation of tidal lands.

A further reference was added under a later warrant dated March 1908 :—

(*e*) Whether in connection with reclaimed lands or otherwise it is desirable to make an experiment in afforestation as a means of increasing employment during periods of depression in the labour market; and, if so, by what authority and under what conditions such experiment should be conducted.

In this final report the evidence is condensed and analysed in a very able manner, and the report contains a large amount of valuable information on the subject of coast erosion, reclamation, and the construction of coast protection works.

The chief recommendation of the Commissioners is that a central Sea-Defence Authority be established for the purpose of administration of the coast-line in the interests of sea defence, and that the Board of Trade be that authority. They recommend that the Board have power to control[1] (*a*) the removal of material and the construction of works on the shores of the kingdom, and (*b*) to supervise and assist, where necessary, existing authorities concerned with coast protection, and to create new authorities where necessary. A very valuable recommendation is also made to the effect that the Board of Trade should " have the assistance of scientific experts to collate information and to secure systematic observations with regard to questions such as the changes taking place below the level of low-water, the travel of materials in deep water, the movements of outlying sandbanks, etc., which are continually happening on the coasts of the kingdom, and with regard to which the information at present is scanty and vague."

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[1] " Royal Commission on Coast Erosion," by Dr J. S. Owens: the *Geographical Journal*, December 1911.

Referring to reclamation, the Commissioners find that there are areas of tidal lands, especially in Ireland, which could be reclaimed with profit to the community. And they suggest that the Board of Trade should be charged with the duty of scheduling and obtaining detailed and scientific reports upon such lands in the United Kingdom as come to their knowledge as being *primâ facie* capable of profitable reclamation, and that in this the Board should obtain the co-operation of the Development Commissioners. In the concluding paragraph of the report it is stated, "we cannot see that there is any grounds for the contention that sea-defence is a national service; it is true that there is serious erosion in places, but this erosion does not affect the nation at large. We therefore recommend that the making of grants from public funds in aid of sea-defence should not be encouraged."

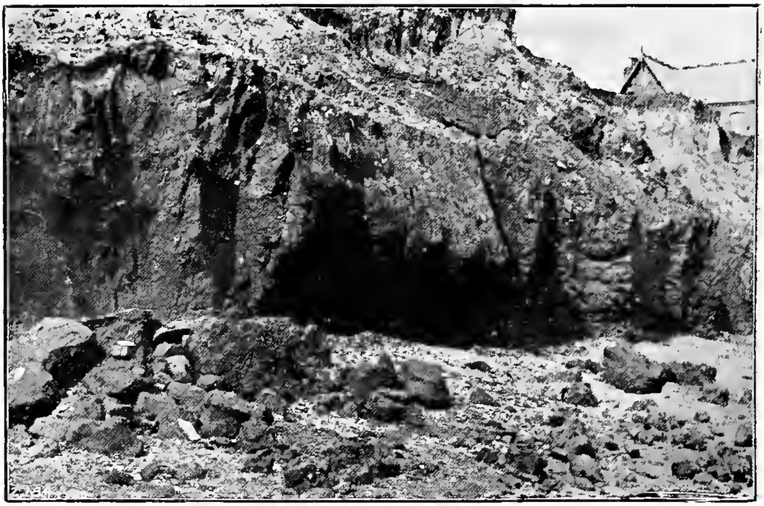
The author would say that he much appreciates the recommendations of the Commission, especially the suggestion that a central authority shall take charge of all matters relating to the protection of our shores, and the suggestion that that authority should be the Board of Trade is a good one, the Board being undoubtedly the best authority to deal with this important matter. It is to be regretted, however, that the Commissioners did not see their way to recommend the giving of a "grant in aid" to those local authorities of coast towns who are so heavily burdened owing to the cost of keeping back the sea, and in some cases also to landowners. Objection of course is raised to the granting of State aid in this way on the ground that any money so granted will be used for the protection of property which does not belong to the State, but which is private property, and private owners are benefited at the expense of the ratepayers at large, without any *quid pro quo.*

This difficulty of justifying State aid under the circumstances is one which is not beyond the power of any Government, and a *primâ facie* case appears to have been made out for assistance in some form or other. In France, Italy, and Belgium the protection of the shores is regarded as a matter of national responsibility. Undoubtedly, if State aid had been granted, some arrangements might have been made whereby the unemployed could have been engaged to assist in the carrying out of the work.

EFFECT OF HARBOUR PROJECTIONS ON COAST LINES.

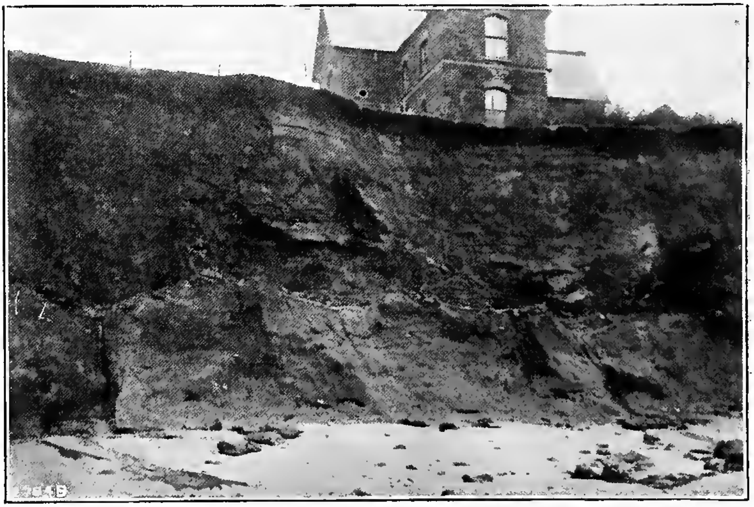
When schemes for the construction of harbours are being considered, the effects upon the coast-line generally of the seaward projection of harbour walls are not always given sufficient consideration. This is a matter of the greatest importance, as it has frequently occurred that until a harbour pier was run out there was no depletion of the beach or erosion of the cliffs. The author's experience has taught him that the usual effect of such a pier is that if the travel of material on that coast is from north to south, as on the East Coast, there is an accumulation of shingle on the north side of the harbour wall, extending northwards to a distance which is regulated entirely by the extent of the projection seawards of the wall; and on the south side there is a depletion and erosion, which extends to a similar or often to a greater distance to the south of the harbour walls. Of course there are exceptions to this rule. Good illustrations of the rule are to be found in the case of the Lowestoft and Madras harbours. The Bridlington harbour affords a less striking example of the same thing, while Shoreham and Yarmouth harbours illustrate this admirably.

If the travel of material along the coast is from west to east, as it is on the South Coast, the banking up will occur on the west side of the harbour. No better example of this can be cited than that of the Hastings partly-constructed harbour. Since the partial erection of the western arm of this harbour the scouring action by the sea on the cliffs immediately to the east of the harbour has been most pronounced, and, in fact, is already a serious matter before the harbour is completed. When the harbour walls are finished, the portion of the foreshore immediately to the west of the harbour will be greatly improved, as there will be a considerable accumulation of shingle on that side of the harbour extending probably a mile westward, but the scouring action on the cliffs to the east of the harbour will be increased.



[*Spurr & Son. Photographers.*

FIG. 25.



[*Spurr & Son, Photographers.*

FIG. 26.

FIGS. 25 AND 26.—THE UNPROTECTED HOLDERNESS COAST.

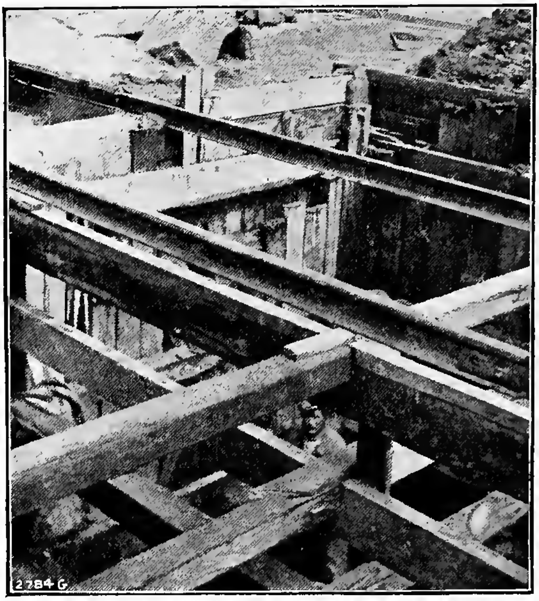
[*To face p.* 35.

CHAPTER IV.

TYPES OF SEA-WALLS.

BEFORE dealing with the construction of sea-walls, it may be emphatically stated that groynes alone are not sufficient for the protection of a coast-line ; they are necessary to keep the beach, but a permanent sea-defence running parallel to the coast is also necessary if the inroads of the sea are to be prevented. As an example, figs. 25 and 26, show two portions of the wasting Holderness coast, where further protection other than groynes would be needed. While on some parts of our coasts, where land of a very moderate value has to be protected, a very much cheaper structure than a sea-wall will answer the purpose, such as a timber sea-defence, or a combination of timber and concrete as will be suggested in a subsequent chapter, the coast-line forming the sea-front of every seaside town of any importance should be protected by a well-built sea-wall. It is proposed to discuss some of the different types of sea-walls which have been constructed around our coasts, and to give a brief description and illustrations of a number of well-built walls. The first class of wall to be dealt with is the stepped type.

Stepped-Face Type.—It will be pretty generally admitted that walls of the stepped-face type are the most satisfactory, as they break up the receding wave, and prevent, to a large extent, that scouring action at the base of a wall which occurs in most of the other designs of walls. Not only so, but if the wall is stone-faced or concrete-block faced, the first cost is usually the last. It must be admitted, however, by those who advocate this class of wall that the reason why stepped walls are not more often adopted is that they are expensive to build, for the reason that the material in the structure is not economically distributed. In spite of this disadvantage, however, the advantages of walls of this type are many. Stepped walls may be faced with stone or concrete blocks; mass concrete is not suitable. Where stone can be brought to the site at a fairly reasonable



[*Waddington & Gibson, Photographers.*

FIG. 29.—FOUNDATION FOR SEA-WALL AT BRIDLINOTON.

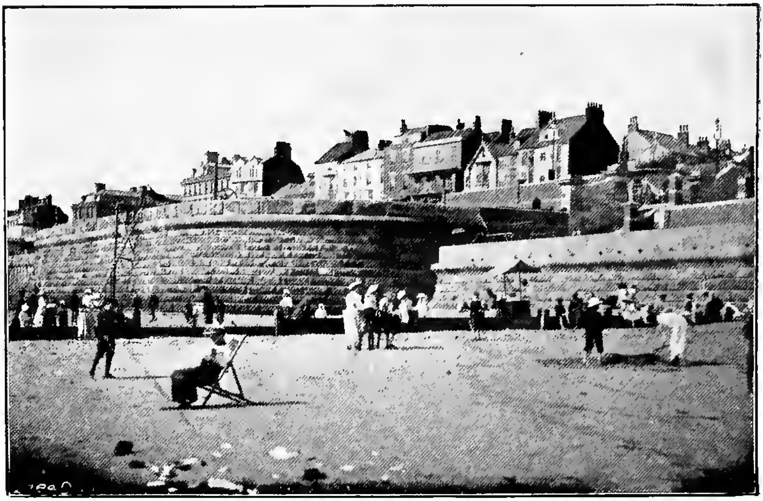


FIG. 27.—ROYAL PRINCE'S PARADE EXTENSION SEA-WALL AND LOW SEA-WALL, BRIDLINGTON.

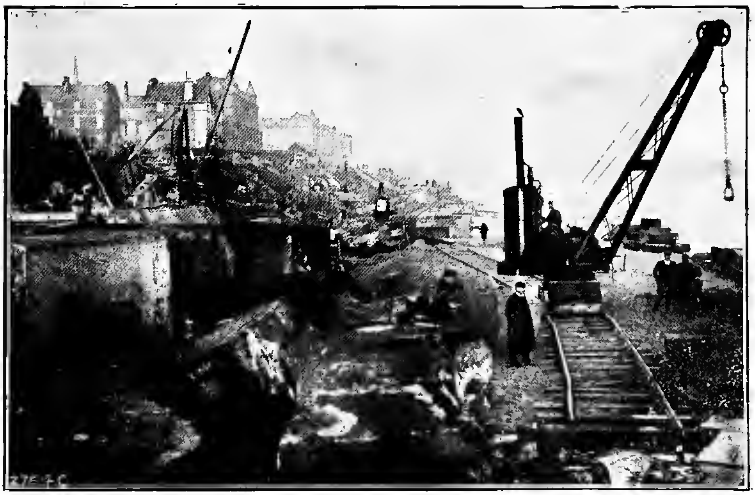


FIG. 28.—ROYAL PRINCE'S PARADE EXTENSION SEA-WALL UNDER CONSTRUCTION AT BRIDLINGTON.

rate, it is better that the wall should be faced with this material—that is, provided a suitable stone be selected. It often occurs, however, that the cost of the carriage of stone prohibits its use. The two sea-walls erected by the author at Bridlington, illustrated in fig. 27, are stone-faced and have concrete backing, and these walls, known locally as the Royal Prince's Parade Extension Sea-Wall and the Low Sea-Wall (Victoria Sea-Defences), will now be described in detail. Fig. 28 shows the Parade Extension under construction, and fig. 29 the method of putting in the foundations, Fig. 30 a cross-section through the former, and fig. 31 a section through the latter.

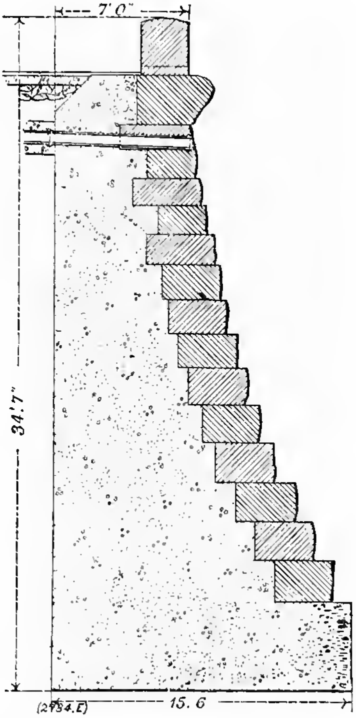


Fig. 30.—Section of Royal Prince's Parade Sea-Wall.

Stepped-Face Walls at Bridlington: Parade Extension Sea-Wall.—This wall (fig. 30) is 355 ft. in length, and has foundations and backing of Portland cement concrete, 6 to 1—viz., 1 part Portland cement, 1 part fine sea-gravel, and 5 parts coarse sea-gravel; the aggregate had to be capable of passing through a $2\frac{1}{2}$-in. ring. The stone with which the wall is faced is Bramley Fall rock-faced stone, and this was used partly with a view of matching the old Prince's Parade wall, which is thus faced. The first six courses are in stretching bond, the stones being not less than 5 ft. long by 3 ft. wide by 1 ft. 10½ in. to 2 ft. 1 in. deep. Then follow three courses, in which the stones are 5 ft. long by 1 ft. 9 in. deep by 3 ft. wide. As to the set-back of each course, this is greatest at the base of the wall and least at the top. The first three courses have a 12-in. set-back, the next two a 9-in., and the following four courses a 6-in. set-back. From the tenth course inclusive and upwards the wall is built in Flemish bond, each header being 3 ft. 6 in. long by 1 ft. 6 in. deep (average) by 2 ft. 6 in. wide on face, the stretchers being 5 ft. long by 1 ft. 6 in. deep (average) by 2 ft. 6 in. wide. These courses have each a 4-in. set-back. In constructing this wall it was necessary to run the courses parallel with those of the old Prince's Parade wall; as the new wall, however, projects further seaward, it

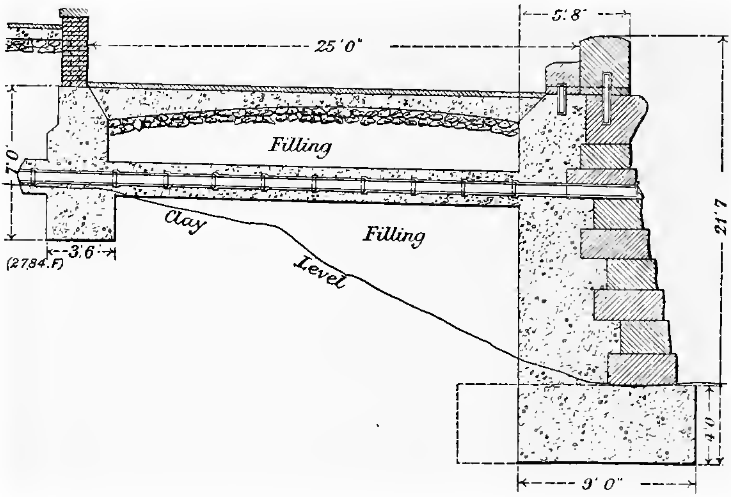


Fig. 31.—Section of Victoria Sea-Defences, Bridlington.

is of greater section than the old. As to the provision for the throwing back of a wave, a dressed cornice is placed on the top of the wall, projecting 15 in. (fig. 30); this is 2 ft. 6 in. in depth, and the length on the face of the stones is not less than 4 ft.; they are also 4 ft. in width, and are bonded to one another horizontally by cement V-shaped dowels 3 in. by 3 in. by 12 in., the holes being cut in the vertical joint of the stone, and cement in a semi-fluid condition poured in.

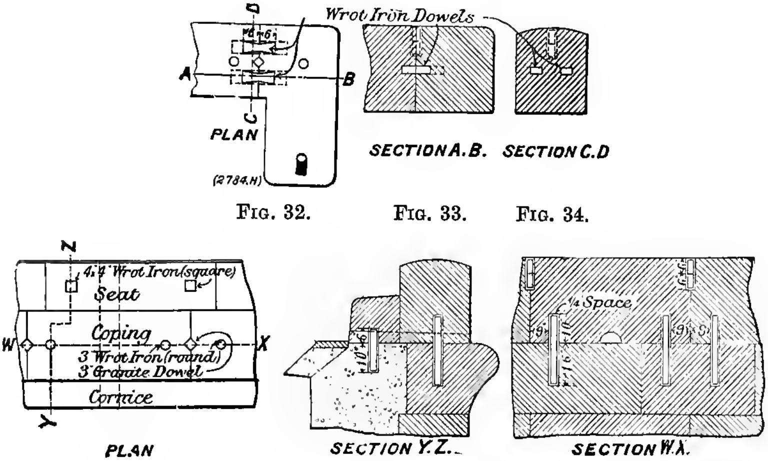


Fig. 32. Fig. 33. Fig. 34.

Fig. 35. Fig. 36. Fig. 37.

Figs. 32 to 37.—Dowels in Coping and Cornice.

The wall is surmounted by a heavy coping, formed of dressed stones, the outside surface being rock-faced and having a 2-in. drafted margin; the coping stones are 3 ft. in depth by 4 ft. in length by 2 ft. 6 in. in width; some of them measure from 7 ft. to 8 ft. in length, and weigh nearly 4 tons. This coping has a bible-back top, which forms a convenient seat. Each stone is bonded to the next horizontally by means of two granite V-dowels, each being 3 in. by 3 in. by 6 in., and set in neat cement; 8-in. semicircular weep-holes were cut through the coping every 6 ft., so as to allow water to run off the parade. All stones were laid on their natural bed, and where the curved portion of the wall occurs, the stones were cut to suit the radii. The top of this new sea-wall is 27 ft. 9 in. above sand level, 29 ft. 9 in. above clay level, 34 ft. 7 in. above the bottom of the foundations, and 17 ft. 6 in. above high-water of spring tides, which reach a level of 10 ft. above Ordnance datum. The top of the foundations was constructed 2 ft. 10 in. below Ordnance datum; high-water of ordinary tides (neap) reaches a level of 6 ft. 6 in. above Ordnance datum. The tide flows for six hours, and ebbs for six, and the range of the tides is about 16 ft. The wall is constructed in plan somewhat in the form of an elliptical curve; the concave and convex curves at the south end of the extension were set out to a 75-ft. 6-in. radius, and the curve at the north end to a 40-ft. radius.

The concrete foundations of the wall were carried well down into the boulder-clay (see fig. 29, page 36); they are 4 ft. 8 in. in depth and 15 ft. 6 in. in width. The portion of the wall at the north end of the extension is built with a vertical face. The face-joints were pointed up with Roman cement. The pointing up of the face-joints of a sea-wall is a very important matter, as there is a danger of air and water penetrating the joints, and by their pressure and elasticity causing stones to move after the blow of a wave. Much damage is often done in this way. Wrought-iron land-ties, 1¾ in. in diameter, were fixed at intervals. This new sea-wall has no apron at its base; the reason for this being that the scour at the base of the wall is really very little, if any, owing to the wall having been designed in the stepped form.

Description of Low Sea-Wall.—This wall is similar in design to the one just described, but is of a much lighter section. It is 455 ft. in length, and is faced with Bramley Fall rock-faced stone (see figs. 27 and 31). It has foundations and backing of 6 to 1 concrete, as previously described for the Prince's Parade sea-wall. The foundations are in the boulder-clay; they are 9 ft. in width and 4 ft. in depth. The top of this wall is 13 ft. above sand level, 16 ft. above clay level, 21 ft. 7 in. above the bottom of the foundations, and 8 ft. above high-water of spring tides, the bottom of the foundations being 3 ft. 7 in. below Ordnance datum. The wall is 8 ft. in thickness at the base and 5 ft. 8 in. at the top.

The wall is a very low one; this was necessary in order to be able to construct terraces at the back of it. If it had not been for that consideration it would have been constructed at least 5 ft., probably 6 ft. or 7 ft., higher. It is, however, 3 ft. higher than the old wooden sea-defence which it replaced. It is most difficult to construct a low wall which will be sufficiently strong to resist the action of the sea; but this difficulty was overcome in the manner to be described. Wrought-iron land-ties, 1¾ in. in diameter, were put in at intervals; some of these were secured to 9-in. by 9-in. pitch-pine piles, and others to the concrete retaining-wall which runs parallel to the low sea-wall, and which was built at the back of the promenade. Six-inch outlets for surface-water (cast-iron pipes of water-main strength) were built into the sea-wall where required, fitted with flaps with gun-metal hinges; 2½-in. trunking-pipes were placed through the wall at an average of 20 ft. apart; they were inserted on a level with the top of the foundations, which was approximately clay level. It is necessary to make ample provision for the carrying off of any subsoil water from the back of a sea-wall. The wall is faced with stone, the courses being built in Flemish bond; the headers are 3 ft. 6 in. in length by 1 ft. 7 in. in the bottom courses, and 1 ft. 6 in. in the top courses by 2 ft. 6 in. on the face, and the stretchers are not less than 5 ft. in length (many are 7 ft. in length) by 1 ft. 7 in. in depth from bottom to top by 2 ft. 6 in. in width. There is a cornice 2 ft. 6 in. in depth on the wall, projecting 12 in. beyond its face; many of the cornice stones are not less than 4 ft. in length by 3 ft. 6 in. in width, and are secured to one another by a cement V-dowel 4 in. by 4 in., except in the parts of the wall that are more likely to be affected by the force of the sea; in these parts the cornice and coping are connected horizontally by means of 3-in. by 3-in. granite dowels, 6 in. long, set in neat cement, two dowels, placed one above the other, being inserted in each joint.

A special feature in this wall is the method adopted to secure the coping stones; these are attached to the cornice by means of 3-in. circular wrought-iron dowels, 2 ft. 6 in. long (figs. 32 to 37), inserted into the cornice to a depth of 18 in., and into the coping to a depth of 12 in., and set in neat cement, the holes in the stone being drilled 3½ in. in diameter in order to allow the cement to form a key around the iron. Two of these dowels were inserted to every coping and cornice stone, and the holes were cut at distances not less than 9 in. from the ends of the stones. The method of fixing these dowels was as follows: Circular holes 18 in. deep having been drilled in the cornice, and holes 12 in. deep in the coping, the dowels were put in position in the coping, the hole in the stone being first filled with fairly stiff neat cement; the dowels were then hammered in. After the dowels had remained for about two days to allow the cement to become well set, the coping stones were picked up by the crane, turned right side up, and dropped into position, a 1-inch neat cement bed having been spread ready to receive them. A V-groove was cut across the top of the cornice stones, leading to the ½-in. cavity which surrounded the dowels, and along this groove liquid cement was run. This method of fixing proved very satisfactory, and, the author believes, was entirely original. To secure these stones still further, 12-in. by 5-in. by 3-in. horizontal wrought-iron dowels in the shape of lewises were also inserted (figs. 32 to 34). It was more difficult to fix these, but the difficulty was overcome by cutting holes 7 in. deep, from back to front, by 6 in. in width by 4 in. in depth in the coping stone which had already been fixed. Corresponding holes opposite to these were cut in the coping about to be put in position; these were 12 in. in depth. The horizontal dowels were temporarily inserted in these holes, and a ⅜-in. diameter wooden runner (about 2½ in. long) was placed under each of the dowels, and attached to the centre of the latter was a copper wire. When the coping stone had been put in position, the wires were pulled and the dowels were drawn into their proper positions. They weigh nearly $\frac{1}{2}$ cwt. each, and were hammered out to shape. The vertical joints between the stones were pointed up with Roman cement, and liquid cement (neat) was poured in at the top joint, filling not only the vertical joint between the two stones, but also the cavity around the dowels; this method of fixing proved quite satisfactory. The cornice and coping were continued around the two flights of steps, and secured in the manner just described, the cornice ending abruptly by means of a specially dressed stop-end. The portion of the wall that is continued around the steps has a vertical face. At the back of the wall, and at the back of the coping surrounding the steps, is a stone seat.

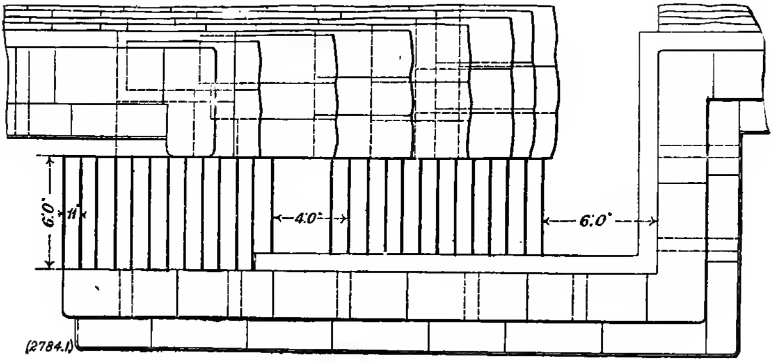


Fig. 38.—Steps Leading to Sands, Bridlington.

Construction of Steps.—Two narrow flights of steps and one broad flight have been built leading to the sands; the former are 6 ft. 2 in. wide (figs. 38 and 39), the latter 15 ft. A flight of steps, 6 ft. 2 in. wide, also leads from the Beaconsfield sea-wall on to the foreshore (figs. 40 and 41). In each case the steps are of Norwegian granite 2 ft. 6 in. in depth by $12\frac{3}{4}$ in. in thickness, and not less than 4 ft. in length. They have 7-in. risers and 11-in. treads, and a ½-in. bed joint of cement. The flights of steps and the landings are supported by a solid bed of concrete, 6 to 1 under the bottom three steps and 9 to 1 under the remaining steps. They are inserted into the walls on each side from 9 in. to 12 in. The cost of these steps in position was 38s. 6d. per lineal yard; to this must be added the cost of the concrete which supports them. The landings were formed of granolithic concrete *in situ*, 2 to 1, 6 in. in thickness, and resting on the 9 to 1 concrete foundations. Concrete formed in this way proves most satisfactory. It should be pointed out that the narrow flights of steps leading from the low sea-wall do not stand out in plan beyond the face of the wall, but are built within the line of the wall. This method should, wherever possible, be adopted, because when they project beyond the face of the wall they cause a scour on the foreshore. The foundations of a flight of steps have been known to be almost undermined by the scour produced by such a projection; sheet-piling and other methods have had to be adopted

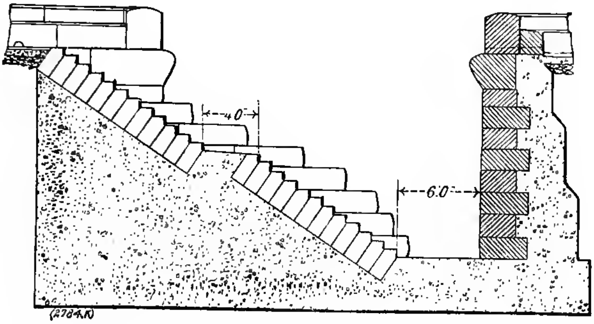


FIG. 39.—STEPS LEADING TO SANDS, BRIDLINGTON.

to prevent this scour. Moreover, when set inside the line of the wall they are protected from the force of the sea.

Concrete Arch.—The promenade at the back of the low sea-wall is supported by a concrete arch (see fig. 31, page 38), which springs from a concrete retaining-wall on one side and from the sea-wall on the other side. This retaining-wall varies in height, but it averages 7 ft. It is constructed of 6 to 1 concrete, has a vertical face and a clay foundation, is 3 ft. 6 in. in thickness at the base and 2 ft. 6 in. at the top. The concrete arch is 9 in. in thickness at the crown, 1 ft. 3 in. at its springing from the low sea-wall, and 1 ft. 9 in. at its springing at the retaining-wall. It is 25 ft. in width, and rests on an under arch formed of 9 in. of block-chalk. There is a fall of 6 in. in the bottom terrace towards the low sea-wall. The author considers that a concrete arch should be put in at the back of a sea-wall wherever the sea is likely to fall frequently with

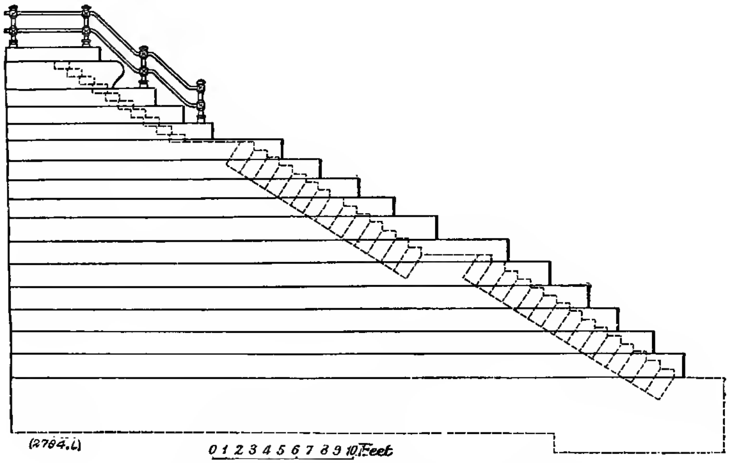


Fig. 40.—Steps Leading to Sands, Bridlington.

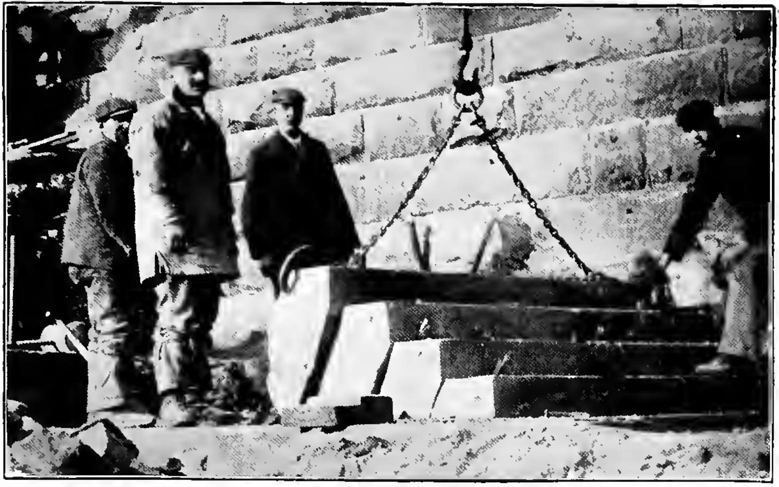


FIG. 41.—STEPS LEADING TO SANDS, BRIDLINGTON.

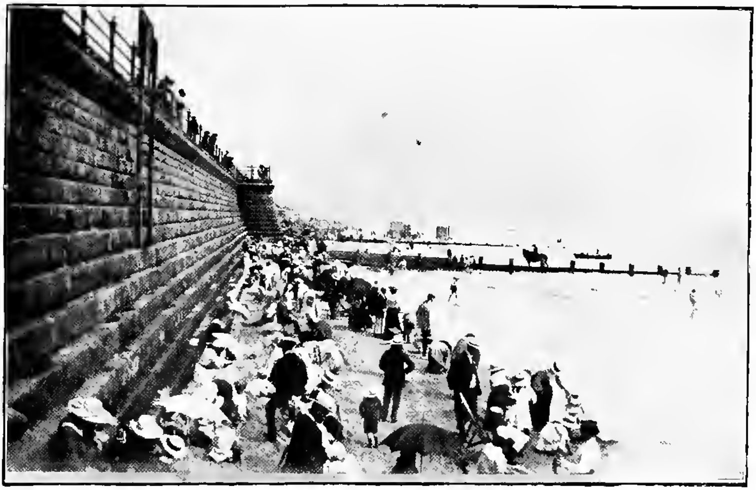


FIG. 43.—PERSPECTIVE VIEW OF BEACONSFIELD SEA-WALL, BRIDLINGTON.

[*To face p.* 46.

considerable weight upon the promenade at the back of such wall. A reinforced-concrete foundation would answer the same purpose. If the filling at the back of the sea-wall settles, the surface of the promenade will not be continually becoming depressed owing to settlement, for the reason that the promenade will be self-supporting. A promenade at the back of a sea-wall should not be constructed with a camber and drained on to gullies, but should have a cross fall towards the sea and discharge direct on to the foreshore. Quite recently the wide walk at the back of the old Prince's Parade wall has been altered by the authors in this way; it was cambered previously. Gullies cannot, during a heavy sea, carry away the water quickly enough.

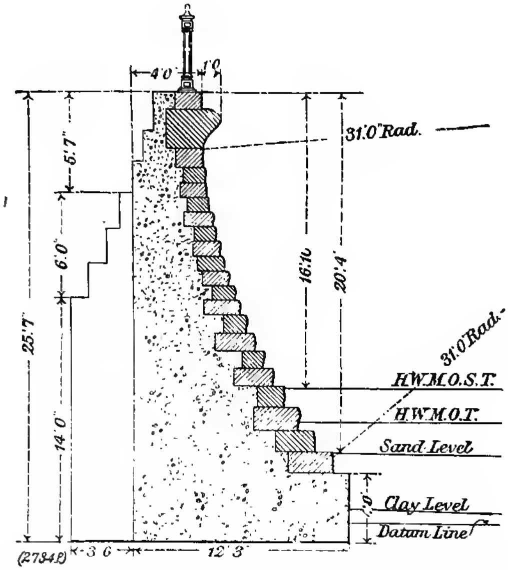


Fig. 42.—Section of Beaconsfield Sea-Wall, Bridlington.

Beaconsfield Sea-Wall, Bridlington.—This wall is illustrated in figs. 42 and 43, and may be briefly described as follows: It is 340 yards in length, and was designed by Mr Samuel Dyer, one of the author's predecessors. It was constructed in 1888 at a cost of £10,000, or £29, 8s. per lineal yard, and is a fine piece of work. It has a stone face of Bramley Fall rock-faced stone with concrete backing. Unlike the new sea-walls just described it has counterforts 20 ft. apart (centre to centre); these are 3 ft. 6 in. by 3 ft. 6 in. As to the face of the wall, the depth of the courses varies from 1 ft. 3 in. for the bottom courses to 10 in. for the top courses. Wrought-iron tie-rods, $1\frac{3}{4}$ in. in diameter, are fixed at intervals. A typical section of this wall is reproduced in fig. 42, on the preceding page, and on this section general dimensions are given. A perspective view of the wall is given in fig. 43. On the dressed coping there is fixed a heavy hand-rail.

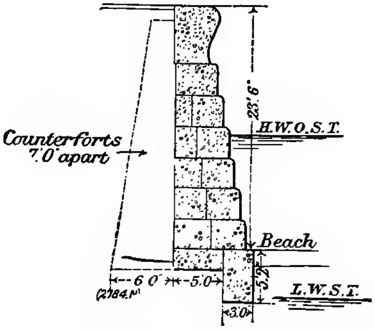


FIG. 44.—CONCRETE-BLOCK WALL AT MARGATE.

Concrete-Block Faced Walls (fig. 44).—Where stone is out of the question, owing to cost, concrete blocks may form the stepped face of the wall. It is preferable that these should be faced with flints, granite spalls, or basalt, to assist in resisting the wearing action of the shingle on the face. They should also be so moulded that each block will key into the next, and it is better that the beds be not too smooth ; this may seem a trifling matter to mention, but it is really very important. The wall at Margate, shown in fig. 44, is faced with concrete blocks, and these are faced with flint.

Smooth-Faced Walls.—A wall with a smooth face, especially if it be a curved face, creates a very much greater scour at the base than a stepped-face wall. Walls built of mass concrete are to be deprecated, as they are a constant source of expense. The Alexandra sea-wall at Bridlington is a good example of the inefficiency of a sea-defence of this type (fig. 45) ; it is a continual expense, the face of the wall having to be frequently repaired. In one winter this was repaired at a cost of over £150 ; it has just been repaired again at a cost of £80. Loose stones upon the foreshore are hurled

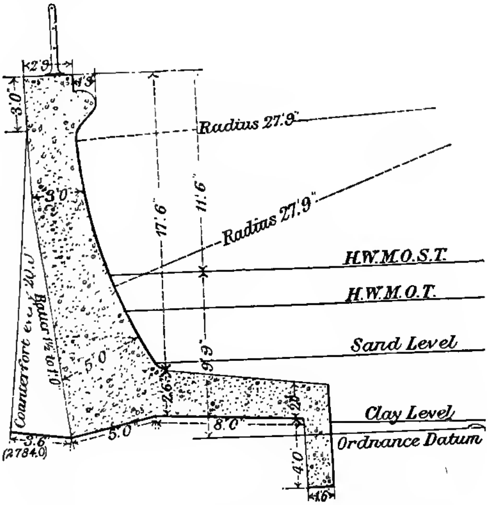


FIG. 45.—ALEXANDRA SEA-WALL, BRIDLINGTON.

with great force during a storm against the face of the wall, the result being that cracks occur in all directions; water and frost get into these, and large pieces of concrete forming the face of the wall break away. This wall, which is 340 yards in length, was constructed in 1879 at a cost of £5657, or £16, 12s. 9d. per lineal yard. It is constructed of Portland cement concrete, and has a concrete apron. The wall is 5 ft. in thickness at the base and 3 ft. at the top; it is curved on the face to a radius of 27 ft. 9 in., the apron is 9 ft. in width and 2 ft. to 2 ft. 6 in. in thickness, the toe-piece being 6 ft. in depth and 1 ft. 6 in. in thickness. The back of the wall is battered 1½ in. in 1 ft. Counterforts are placed at 20-ft. centres, and chains are inserted in the wall to act as bonds for the concrete. The wall has a projecting cornice, and a coping upon which there is a heavy iron hand-rail. In favour of a wall of this type it has been suggested that concrete in mass has a great advantage over masonry walls, in that it has no joints for the sea to play upon. This may be a slight advantage, but the disadvantages are so many that the author considers that this slight advantage counts for very little.

Stone-Faced Walls.—The most suitable stone with which to face a sea-wall is undoubtedly basalt or granite, especially where the shore is chiefly shingle, and high-water of spring tides rises to several feet up the wall. Where a sea-wall has been faced with concrete blocks, the force with which the shingle was hurled against the wall during a heavy sea has been known completely to tear out the outer half of one of the concrete blocks and severely to damage several others. With a stone face such an occurrence as this would be impossible, especially if the wall was faced with granite or basalt ; but of course the cost of these materials largely prohibits their use. In Holland and Belgium the sea-walls are mostly built with a big slope, about 1 in 2 forming a masonry embankment. The foot of the wall is protected from the scour of the waves by an apron, which is usually faced with pitching, generally basalt. The author is now constructing a wall of this type at one of our coast towns where the range of the tides is very limited, and high-water of ordinary spring tides only rises about 3 feet up the wall. A brief description of one or two walls of this class will now be given.

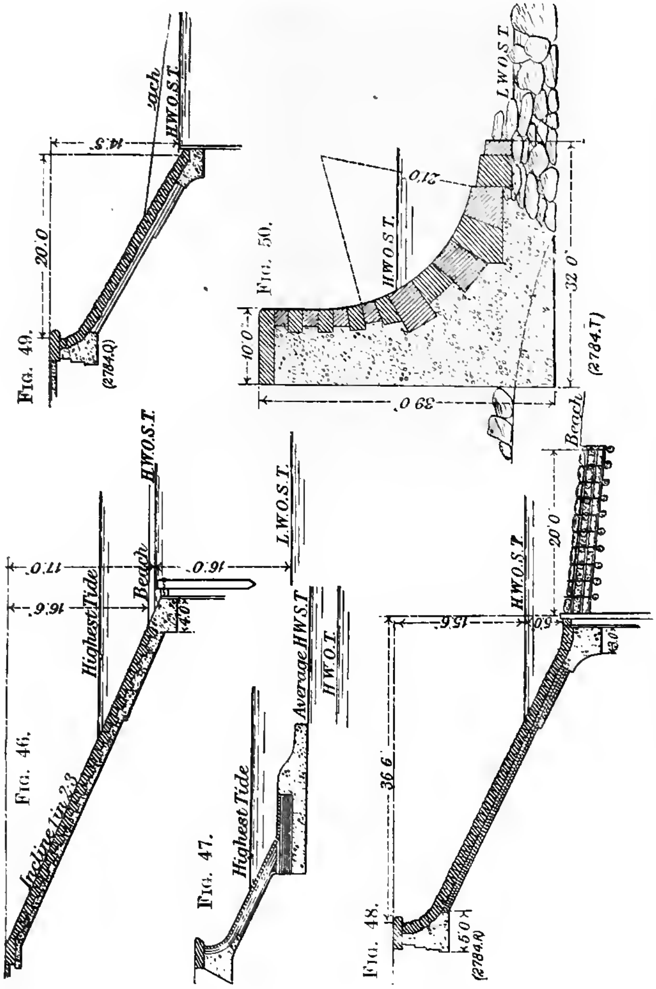
CHAPTER V.

TYPES OF SEA-WALLS—(*continued*).

Blankenberghe Sea-Wall. — Fig. 46, on opposite page, represents a section through one of the sea-walls at Blankenberghe. This has a batter of 1 in 2·3, and is faced with stone which rests on a concrete slope. The toe of the wall is protected by sheet-piling and by a row of piles which are driven in front of this. The height of the wall above beach level is 16 ft. 6 in., above high-water of ordinary spring tides 17 ft., and it is surmounted by a heavy stone coping.

Ostend Sea-Wall.—A sea-wall at Ostend is illustrated in fig. 47. This wall is faced with brick-on-edge on concrete, and is surmounted by stone coping, under which is built up a low masonry wall. In fig. 48 is shown another sea-wall at Ostend, which is built upon a somewhat different principle. The slope is faced with masonry, which rests upon a brick-on-edge foundation. Sheet-piling protects the toe of the wall, and seaward of this, and extending about 20 ft., is fascine work with stone pitching. The wall has a batter of 1 in 2, and the stone coping is supported by a dwarf concrete wall. The wall extends seaward a distance of 36 ft. 6 in.

Mariakerke.—The wall shown in fig. 49 is similar to those just described. It is faced with masonry resting on brickwork, and has at its toe sheet-piling and concrete. It projects 20 ft. seaward, and is 14 ft. 3 in. in height above high-water of ordinary spring tides.



Figs. 46 to 50.—Sections of Sloped and Curved-Face Sea-Walls, with Aprons Faced with Pitching.

There are a few walls of this type in this country, one being at Blackpool. A wall of this description may be suitable where sand-dunes have to be faced, as in Belgium and Holland; but in this country is open to the following objections:—

(*a*) It would need continual repairs. When the sea once breaks through it lifts the sloping face of a wall of this description, and bulges it out, so that it has to be ripped off and reconstructed.

(*b*) It is unsightly.

(*c*) When a wave breaks on the sloping face of such a wall the whole structure appears to vibrate, and, should there be a weak place, the waves will soon find it out, and much damage during a heavy sea will be done.

(*d*) A wall of this type extends further seaward than an upright wall, and therefore the force of the waves acts on it for a longer period.

(*e*) The waves also have a tendency to tear out any of the pitching that happens to work loose. There is only the weight of the individual stones and their cement bed to keep them down. There is no weight of a wall above them to hold them in position. Mr Thomas Stevenson found that the horizontal force of the back draught of a wave was equal to three times the direct force, and it is this recoil of the wave that has a tendency to tear out the stones on the sloping wall. Some very interesting experiments were carried out in 1855 by Mr Brunlees to ascertain the force required to draw facing-bricks out from a wall, 4 ft. high, having various batters. Fire-bricks, 9 in. in depth, were placed on end, and a chain which worked over a pulley was attached to the centre of the brick; the average pull to extract the brick was as follows:—

Slope.	Pull required to extract brick. lb.
1 to 1	105
2 ,, 1	148
3 ,, 1	144
4 ,, 1	198

Mr Brunlees concludes his paper[1] by stating that in his opinion the best form of slope effectually to resist the action of the waves was a steep slope of 2 to 1 with heavy pitching. Most of the Continental types of sea-walls have a slope of about 2 to 1.

(*f*) Should a slight crack occur on the sloping face of the Continental type of wall, the waves, breaking with great force on it, would have a much greater tendency to open it out than would be the case if a similar crack occurred in an upright or nearly upright wall.

(*g*) The advancing and the retreating waves meet upon the slope, the result being that the former breaks with a greater force than would otherwise be the case.

The stepped form of wall has been objected to on the ground that it affords a broken surface for the waves to act on, and as the stones are not placed directly over each other, the superincumbent weight, which, in a vertical wall, assists in keeping the lower stones in their places, is not available to secure rigidity. With regard to the first objection, one of the greatest advantages claimed for this type of wall is that it has a broken surface for the waves to act on, thereby breaking up the wave as it strikes, and, what is even more important, reducing the scour at the base of the wall by catching the water on the steps as it falls; no other type of wall gives these advantageous results. The author considers the second objection to be merely theoretical, as in practice no detrimental effect results from the arrangement.

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[1] *Minutes of Proceedings of the Institution of Civil Engineers*, vol. xiv.

Protective Aprons.—A stepped-face wall seldom requires an apron to prevent scouring at the base of the wall; where such an apron is essential this should also be stepped.

A concrete or masonry apron with a sloped or curved profile only tends to increase the velocity of the receding wave, and to cause a scour at the toe of the apron. As an argument in favour of a concave profile, it is claimed that as the wave travels forward it is guided upward by the curved apron, and that as it recedes so rapidly, owing to the smooth face of the wall, the force of the incoming wave is broken up before it reaches the wall.

The objections to this class of apron are:—

1. The receding wave travels so rapidly down the curved face of the wall that great scour often takes place at the toe of the wall. The Alexandra sea-wall at Bridlington is a good example of this. Sheet-piling in some cases has had to be added when aprons of this class have been put in.

2. The incoming wave, being guided by the curved profile in an upward direction, rises higher, and consequently falls with greater force upon the apron or just clear of the wall, and so increases the scour in that way also.

Curved-Face Walls.—Many excellent examples of curved-face walls might be given, some of the best-known examples in this country being found at Scarborough—the new Marine Drive sea-wall,—at Blackpool, and at Hastings.

Marine Drive Sea-Wall at Scarborough.—This is illustrated in fig. 50, on page 53, and is a fine piece of engineering work. In the author's opinion, it possesses two serious defects. One is that the greater portion of the water falling on to the roadway at the back of this wall has to be carried off by gullies. It is far preferable for the roadway to be constructed with a direct fall to the sea-wall, so that a wave falling on to the roadway will have run off before the next wave arrives. The other objection will be referred to later.

The Marine Drive sea-wall, which is built upon the Oxford clay or blue shale, is about 4200 ft. in length, its height varying from 22 ft. to 40 ft. In some portions of its length the foundations of the wall are below low-water of spring tides, and it was that fact that made the carrying out of the work so difficult and prolonged. As to the profile of the wall, it has a concave face; it is faced with huge concrete blocks, 6 to 1, backed up with mass concrete, 8 to 1. The blocks vary in weight, the foundation blocks being 9 tons, while the lightest face blocks weigh 1½ tons. Every block is keyed into the next with a cement dowell and the joints are pointed up with Roman cement. With regard to the filling at the back of the wall, this consists largely of material (rocks, etc.) from the face of the cliffs. There is a promenade and carriage-drive at the back of the wall. Considerable damage has been done to this important sea-defence since its construction. Shortly after the wall was completed (in January 1905) a severe storm occurred, which caused a portion of the wall—some 540 ft. in length—to move slightly seaward. The width of the promenade is 20 ft., and it is paved with 8 to 1 concrete *in situ.* The roadway is 40 ft. in width, and in the more exposed portions of the work it is paved with concrete blocks 2 ft. by 1 ft. by 7 in., laid on a bed, 12 in. in thickness, formed of 8 to 1 concrete. Where the roadway is less exposed to damage by the sea it is finished with 4½ in. of tar paving. The face of the cliffs is drained into a 12-in. stoneware pipe drain, which is surrounded by rubble. This drain discharges into manholes fitted with tide-flaps, and the ultimate discharge is by means of outlets through the sea-wall into the sea. The railings erected on the top of the sea-wall are of a heavy pattern, the cast-iron standards being fixed 7 ft. apart, and carrying three horizontals of stout tubing. Owing to the damage done to these standards by the sea, they are gradually being replaced by wrought-iron standards. The cost of carrying out the important works just described was as follows: New Marine Drive, from junction of the Royal Albert Drive to the East Pier (1400 yards in length), £102,400; the forming of an approach road from the East Pier to the south foreshore alongside the harbour, £17,161. Fig. 1A represents a record wave striking the new sea-wall.

Clacton-on-Sea.—The curved-face wall at Clacton, which is illustrated in fig. 51, was constructed about thirteen years ago, and is similar in section to an older wall which was erected twenty-nine years ago. It has a batter of 1 to 1, and its base is protected by a concrete apron. The wall is faced with masonry, and the toe of the apron is protected by sheet-piling. At ordinary spring tides the water rises about 5 ft. up this wall.

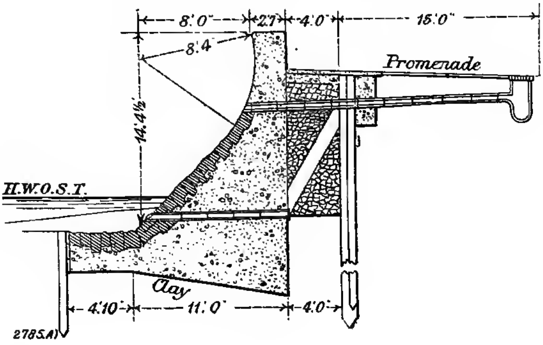


Fig. 51.

Fig. 52 shows a Continental type of wall with a curved face and a stone-faced apron.

Paving on Promenades.—With regard to paving on

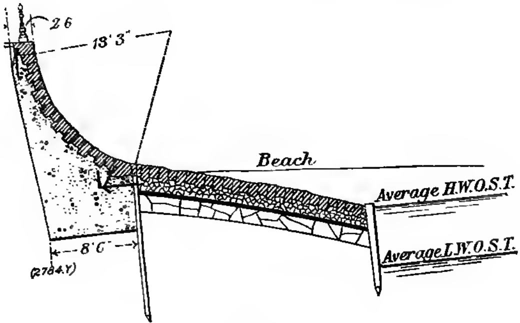
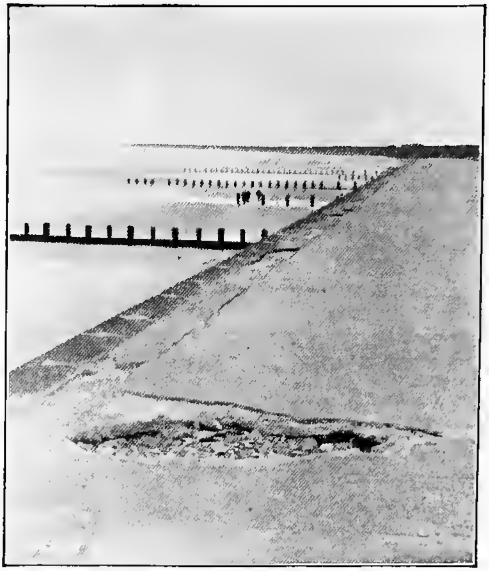


Fig. 52.

promenades on sea-walls, asphalt is not a good material to resist the action of sea-water, flagging on concrete, or concrete *in situ*, being far preferable. If the latter is used, great care should be taken to see that the concrete is put in at least 6 in. in thickness, preferably 8 in., and in one layer, and that a careful selection of the aggregate is made. No chalk stone should be used on any account. The effect of using gravel which contains a large proportion of chalk for the aggregate, and of putting in the concrete of insufficient thickness, is well illustrated in fig. 53, which represents the promenade at the back of a sea-wall on the East Coast. Expansion joints should be inserted, say, every 10 ft.



[*White, Bridlington, Photographer.*

FIG. 53.—CONCRETE INSUFFICIENTLY THICK.

Morecambe.—Fig. 54, page 61, is an example of a curved-face wall and represents a typical cross-section through the wall. This wall has recently been erected by the borough engineer, Mr J. W. Hipwood, A.M.Inst.C.E., and was also designed by him. It may be briefly described as follows:—It is entirely in concrete, 6 to 1 throughout, with the exception of the facing, which is formed with 3 to 1 concrete, to a thickness of 6 ins. This was, of course, put in concurrently with the remainder of the sea-wall, and gives an excellent monolithic result. The sheeting to the face work was carefully done, so as to leave no board mark on the concrete face, which was afterwards twice cement-washed. Weep-holes are spaced at intervals, the outlet flaps being chained down, allowing them to open slightly, but preventing the tide, shingle, and sand getting past them. The coping, which is somewhat light, being only 15 in. by 8 in., is dowelled into the concrete wall, and is also well cramped at the bottom with iron ties of dove-tail shape.

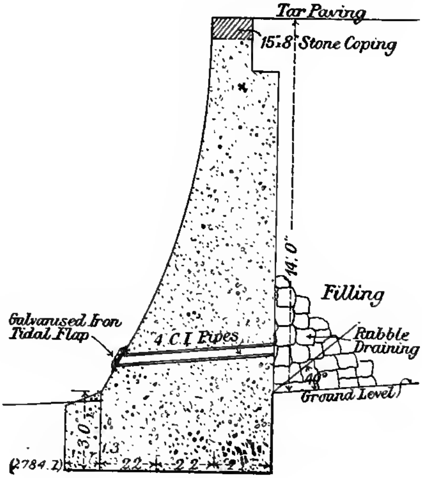


Fig. 54.

Blackpool.—Figs. 55 to 61 illustrate the sea-walls constructed by the Blackpool Corporation since 1902, and designed by their borough engineer, Mr John S. Brodie, M.Inst.C.E., the work being executed under his direct supervision. It may here be said that it would be difficult to find around our coast sea-defence works which have been carried out in a more thorough manner than those at Blackpool about to be described. The special feature about the walls and aprons is that they are faced with basalt columnar stone, which is undoubtedly the very best material with which to face a sea-wall; the hexagonal shape of the stones makes also a good key. It is a better stone than granite, being much denser; the cost, however, precludes the use of this material in most cases. Several harbour and dock-walls in this country are faced with basalt. The main length of wall was commenced at South Shore in the spring of 1902, and completed and opened in July 1905, as far as the North Pier, a distance of 3184 lineal yards. A sea-wall, 400 lineal yards in length, from the north end of the North Shore Works to the northern boundary of the borough, was commenced in August 1910 and completed in January 1911, surely a record rate of progress. The sea-wall from the North Pier to Cocker Street (the southerly end of the North Shore Works), a length of 400 lineal yards, was commenced in October 1910. This completes the large undertaking, begun ten years ago, of widening the promenade between the South Shore and the North Pier. The total cost of the before-named work amounted to approximately £370,000.

Fig. 55, opposite page, shows the general section of the sea-wall, a length of 2384 lineal yards, from the Victoria Pier to the Central Pier. Fig. 56 shows the section between the Central Pier and the North Pier, a length of 800 lineal yards; and fig. 57 shows the section beween the North Pier and Cocker Street, a length of 400 lineal yards. Solidity of construction, having due regard to economy of expenditure, has been

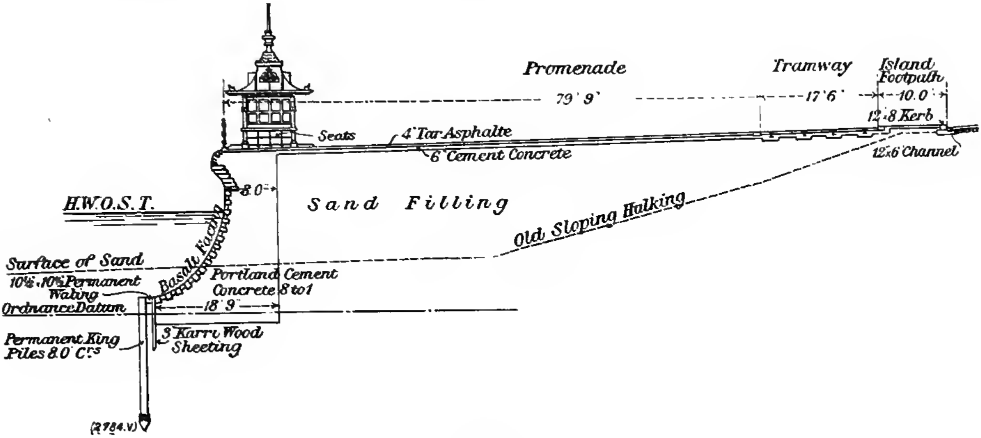


Fig. 55.

aimed at in each section, and as a sound foundation is the main essential in sea-wall construction, the wall was

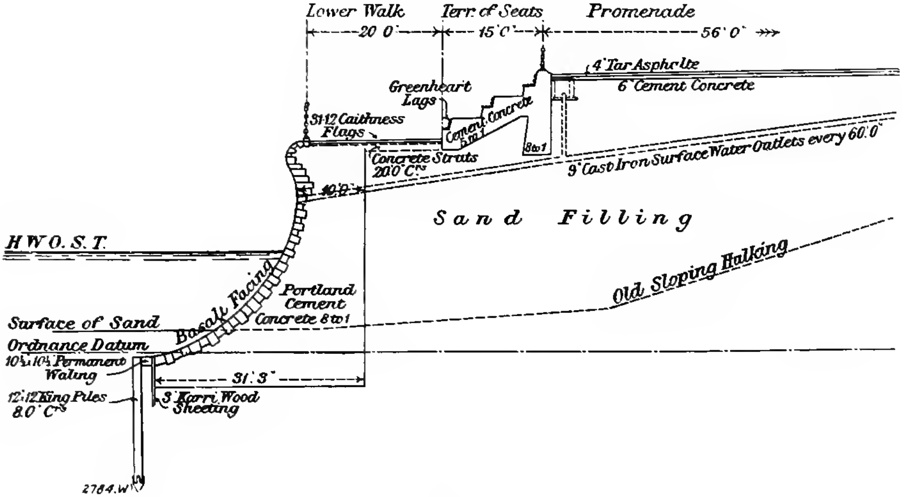


Fig. 56.

taken well into the clay, the whole-timber king-piles driven 20 ft. below toe level and spaced at 8-ft. centres.

Permanent whole-timber walings were bolted to the king-piles and sheeting piles spiked to the waling. The walls and aprons were bedded and grouted in Portland cement mortar. No expenditure on maintenance has been necessary on the above sea-walls, some of which have been completed now for upwards of seven years. The new Princes Parade, opened on May 1, 1912, is entirely a reclamation from the sea, 5¼ acres of promenading space being added to the already extensive promenade. Seating accommodation is added for 6000 people, and two large garden spaces have been laid out. In this part of Blackpool's huge sea-front improvement works no less than 33,500 cubic yards of concrete, 6000 tons of basalt stone, and 160,000 cubic yards of sand filling were used. Figs. 58 to 61 show the promenade at Blackpool under extreme aspects. Figs. 58 and 59 will give an indication of the violence of the storms which sometimes beat upon that shore, rendering the building of sea-defences difficult and

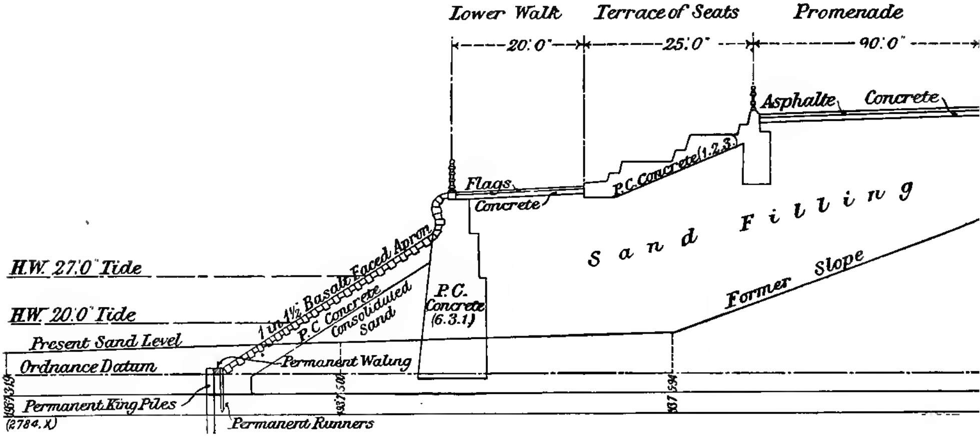
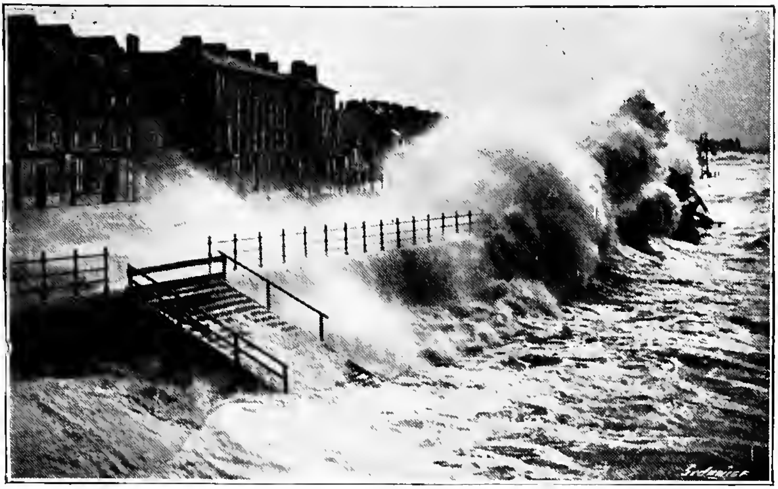
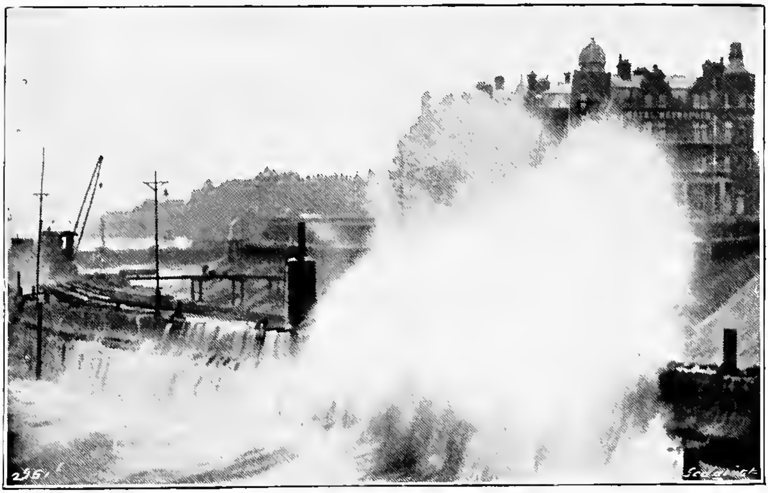


Fig. 57.



[*E. Wolstenholme, Photographer.*

FIG. 58.

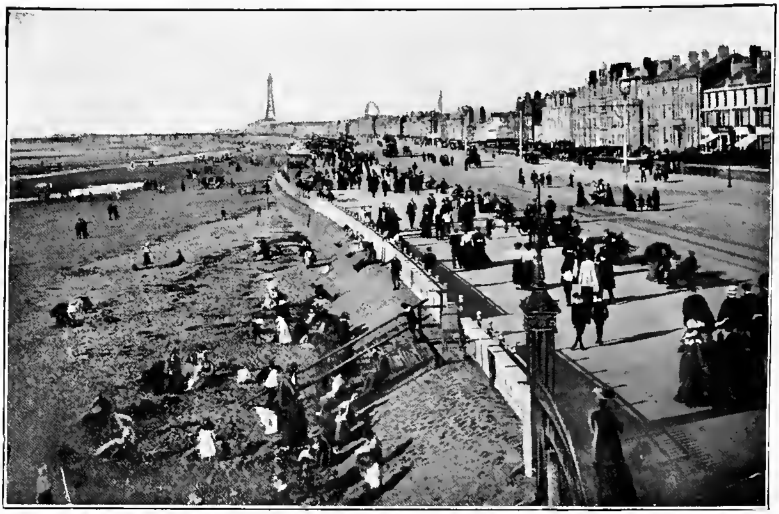


[*E. Wolstenholme, Photographer.*

FIG. 59.

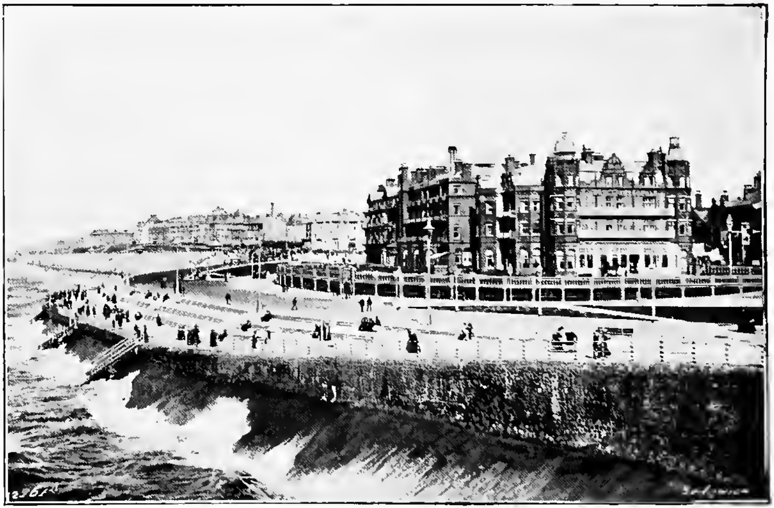
FIGS. 58 AND 59.—THE SEA-DEFENCES OF BLACKPOOL.

[*To face p.* 64.



[*R. Berry, Photographer.*

FIG. 60.



[*W. P. Beck Photographer.*

FIG. 61.

FIGS. 60 AND 61.—THE SEA-DEFENCES OF BLACKPOOL.

[*To face p.* 65.

dangerous; whilst figs. 60 and 61 present the finished promenade under summer conditions.

In the Blackpool sea-walls provision is made for the throwing back of a wave after it has struck the face of the wall. At Scarborough, after a heavy sea has struck the wall, the water is thrown to a great height vertically (see fig. 50), and a large portion of it falls upon the roadway at the back of the wall; on one occasion the author noticed that the road had collapsed under this great force, and had sunk in places nearly 3 ft. Unless some such provision is made as at Blackpool for the throwing back of the wave, it is a mistake to erect on top of a sea-wall cast-iron standards and wrought-iron railings. At Scarborough, on the wall referred to, during one storm, nearly 150 standards were broken and the iron railings twisted in all shapes.

CHAPTER VI.

REINFORCED-CONCRETE SEA-DEFENCES.

De Muralt's Systems.—In many of the embankments, or dykes, in Holland, as we have already stated, the slopes are faced with basalt, or other natural stone, which is a very expensive process; dunes have also been pitched in this way. This method is a very good one, provided the pitching is placed on a good foundation. The foundations are usually prepared as follows:—First, the slope is formed of clay, levelled and provided with a layer of straw, whereon two layers of brick are placed. On this brick foundation a deposit of brick rubbish is spread, and on this the stones of basalt are firmly set. The same method is used in the defence of the dunes; but because these consist of sand, the slope of the dune is first covered with a layer of clay to the thickness of about 50 cm., on which the basalt slope is then laid in the same manner as with the sea-dyke. The basalt slopes for the seriously attacked sea-dykes cost in Holland 5 to 8 guilders (8s. 4d. to 13s. 4d.) per square metre; while the construction of basalt slopes for the dunes, inclusive of the covering with clay, demands an expenditure of 9 to 12 guilders per square metre. Some interesting particulars as to the cost of facing dykes with basalt in Holland were given by Mr. A. E. Carey, M.Inst.C.E., in a paper read before the Institution of Civil Engineers in December 1910.[1] The following is an extract from his paper: "Basalt has been in use for about forty-five years; before that a limestone rock from Dornik was principally used. Taking a typical case, the cost of a covering such as that described is:—

	Per Square Yard. s.	d.
Clay	3	6
Straw cover	0	2
Brick tiling	1	4½
Basalt pitching	9	9
Labour	1	1½
Total	15	11

Mr R. F. Grantham says: "As a comparison with this we might say that the cost of stone pitching in Essex was 4s. 6d. per square yard"; but in the author's opinion this is too low an estimate.

In Holland basalt slopes have been mostly abandoned for the defence of dunes, and reinforced concrete has been substituted. Reinforced concrete lends itself admirably for the construction of sea-defences; it has been used for this purpose in Holland, Germany, and France, and there are several interesting examples of its use in this country, notably at Thames Haven, Tilbury, Aldeburgh, and Southwold. Among these instances are the well-known Dutch systems of foreshore protection, known as De Muralt's systems. One of these systems consists of the defence of slopes and embankments by means of concrete reinforced with expanded metal or with iron rods (see figs. 62 and 63). The inventor claims for it the following advantages :—

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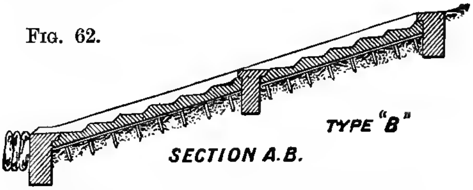
[1] "The Winning of Coastal Lands in Holland," by Alfred Edward Carey, M.Inst.C.E. *Minutes of the Proceedings of the Institution of Civil Engineers*, 1910, vol. clxxxiv.

1. The construction and the principle upon which it is carried out obviate the difficulties appertaining to other concrete slope defences.

Fig. 62.



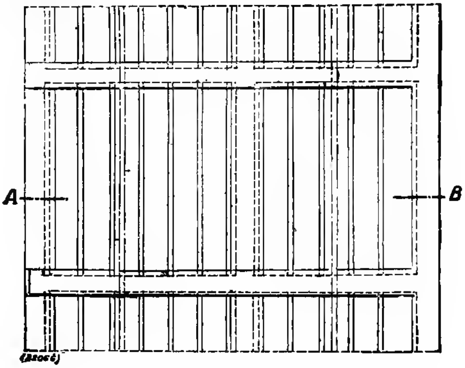


Fig. 63.

2. The remarkably simple construction allows it to be carried out by unskilled labour.

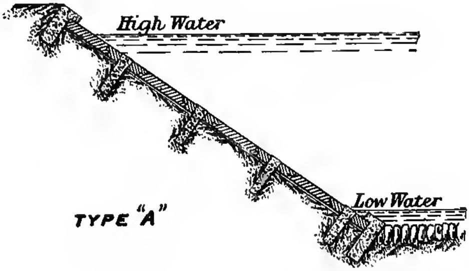
3. Slopes protected on this system offer great resistance to wave-action.

4. A greater economy than with other systems.

The cracking of the concrete in consequence of contraction and expansion is obviated by dividing the slope-facing into small separate sections, the reinforced-concrete facing being no longer monolithic, as is usual, but consisting of a number of separate slabs kept in place by a system of beams, the whole being constructed *in situ* with an extremely small amount of plant or form-work. De Muralt's system of building the beams on the slabs, and not the slabs on the beams, thereby weighing down the slabs by the beams, is not only different from other reinforced-concrete systems, but has great advantages. Practically the whole of the concrete work can be done on the slope itself very cheaply, and simple forms can be utilised. The division of the slope-facing is the ruling idea of this system of construction, and this is obtained by building beams all around and resting on the slabs (see fig. 67, type B).

The method of construction of type A is as follows:— The soil of the slope is first carefully graded. After this has been done, two notched or stepped wooden beams, 10 cm. by 12·5 cm., are laid parallel to each other at exactly 1·8 m. (70 in.) apart, extending up the slope. The length of these stepped beams is 2·8 m. (110 in.). The beams having been secured in position by iron stakes, a thin layer of concrete, 2·5 cm. thick, is laid on the slope, and on this a sheet of expanded metal is laid. Instead of expanded metal a reinforcement of iron rods woven into meshwork is sometimes used. When the reinforcement is in position, a board with a fillet is placed against the cleats on the lowest steps of the notched beams and concrete is rammed beneath it; boards are afterwards placed on each step as the concreting is carried up the slope; they are held in position by means of iron handles, through which wedges are driven. The concrete is carefully punned by means of iron rammers, each step being concreted in succession until the whole slab is completed. When the work of construction is subject to submersion at high tide, the wooden forms should not be removed for twenty-four hours. Fig. 68 shows a slab completed; it bears a strong resemblance to a flight of stairs, the thickness varying from 7·5 cm. to 12·5 cm. (3 in. to 5 in.). The forms are all made of fir, and the iron stakes used to fix the beams in place measure 4 in. in length and are nearly 1 in. in diameter. Should the slope-facing consist of more than one row of slabs, such as two parallel rows, for instance, the slabs would be concreted the whole way up the slope between two long notched or stepped beams, the slabs being separated by a horizontal space. Reinforcement consisting of iron rods is better for the framing beams. The hardening of the slabs should have been continued for some days before the construction of the beams is commenced, and each step should have a 1½-in. chamfer. The forms should be well oiled to prevent the concrete adhering thereto. All the slabs should be independent of one another, and also the framing. When working on a sand-dune, it is of the greatest importance to construct the footing before the slabs, in order to prevent the sand sliding down under the finished lower slabs. Should the work be undertaken on the seashore, where the tide continuously washes the slope, more wooden forms are necessary, because the slabs must remain covered during at least one tide, and the forms should be weighted with heavy rock to prevent them being washed away. The concrete used in constructing this class of sea-defence or river-bank protection is composed of 3 parts Portland cement, 4 parts sand, 1 part trass, 7 parts gravel, and mixed with sea or river water.

Fig. 64.



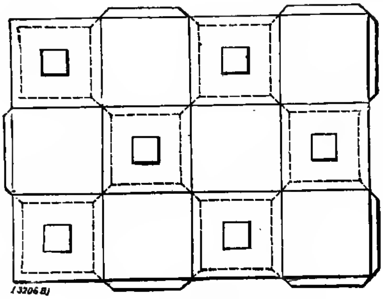


Fig. 65.

This system of coast-defence is a very suitable method

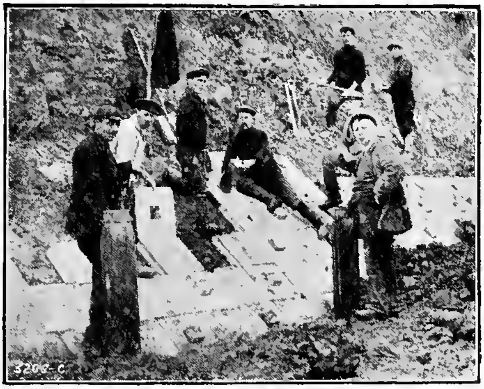


Fig. 66.—Type A.

for protecting agricultural land, as the work can be executed with great ecomomy and efficiency. The only objection to employing this for the protection of the sea-front of a town is the question of appearance and space occupied by the protective works. The concrete-keyed-tile system of Muralt (see figs. 64, 65, 66, and 67) is useful for facing the slope of a cliff above where wave-action operates, or for replacing the pitching on river banks, and this system is strongly advocated for the preservation of river embankments, for which it is admirably suited. Fig. 69 illustrates a protected slope at Tilbury. It is carried out by facing the embankment with concrete tiles; these are keyed to one another, and are secured to the embankment by means of concrete stakes. The toe

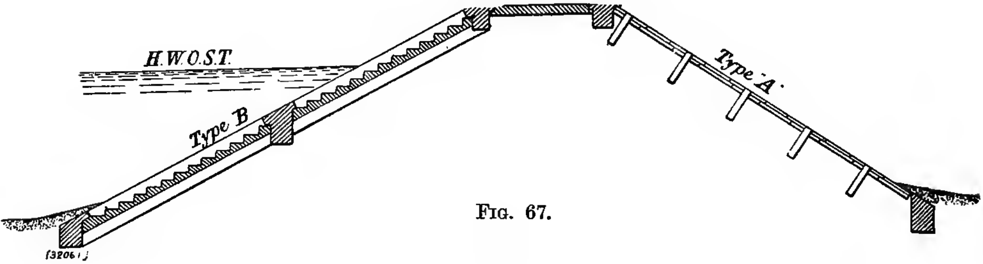


FIG. 67.

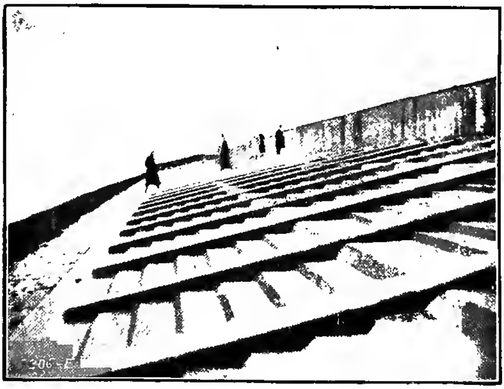


FIG. 68.—TYPE B.

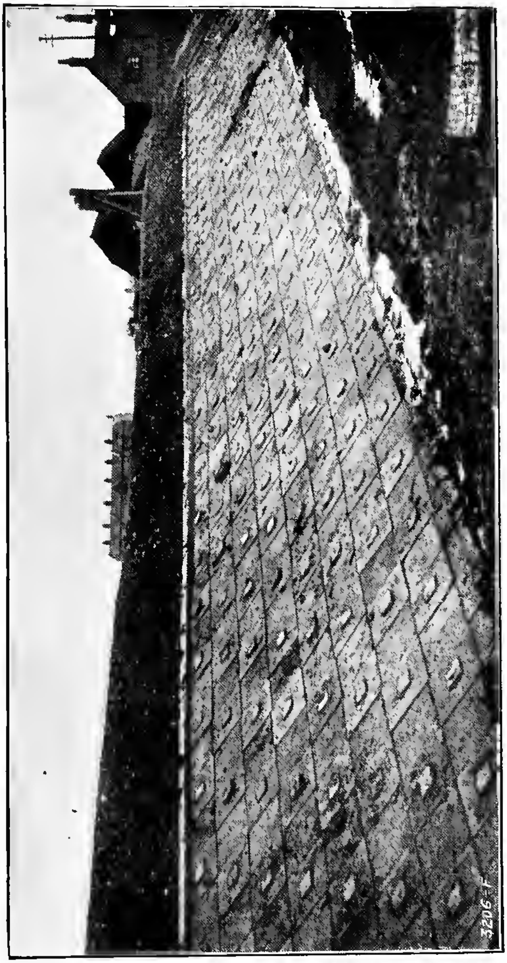


FIG. 69.—PROTECTED SLOPE AT TILBURY.

of the slope is protected as shown in fig. 64, and also the top of the embankment The work was finished in 1910. Mr Carey states in his paper, previously referred to, that the Osse breakwater, constructed on this system, cost £1, 11s. 5d. per lineal foot, the corresponding estimate for basalt pitching being £3, 12s. per lineal foot.

Sea-Wall at Hornsea, Yorkshire.—One of the best examples in this country of sea-wall construction where reinforced concrete has been introduced in a part of the structure is the new sea-wall at Hornsea, Yorkshire, designed by Mr W. T. Douglass, M.Inst.C.E.; this is illustrated in fig. 70. The old sea-defences, which were of a very temporary character, were practically destroyed by the severe gales in 1906 (see fig. 71), which storms also worked havoc upon the cliffs of Holderness to the north and south of Hornsea. Some idea of the damage done on the sea-front of this Yorkshire town may be gathered from this view. The new works, which are fulfilling their purpose very efficiently, were commenced soon after the severest storm occurred in 1906, and were completed during the summer of 1907. The lower sea-wall is of plain concrete, the upper wall being reinforced by the insertion of expanded metal and steel rods. The sea-wall is 720 ft. in length, and when the wall was erected three new groynes were also put down. These are 745 ft., 430 ft., and 400 ft. in length respectively, and will be referred to again later in the chapter on Groynes. The outlay on the works (including the three groynes), Mr Douglass tells us in his paper on "Coast Erosion," read before the Institution of Civil Engineers on February 21, 1911, was £10,820.

Reinforced-Concrete Sea-Walls at Hartlepool.—

Another good example of the use of reinforced concrete in shore-protection works is to be found at West Hartlepool. The structure was designed by the Borough Engineer. The reinforcement used was expanded metal. A row of 12-in. by 12-in. timber piles, each 9 ft. long and spaced at 9-ft. centres, was driven at the foot of the slope; behind these, 12-in. by 6-in. walings were spiked, and these form a protection for the toe of the structure, and also prevent sliding action occurring. The average height of the sea-wall above the level of the top of the piles is 13 ft. 8 in.; the foundation slab is 6 in. in thickness.

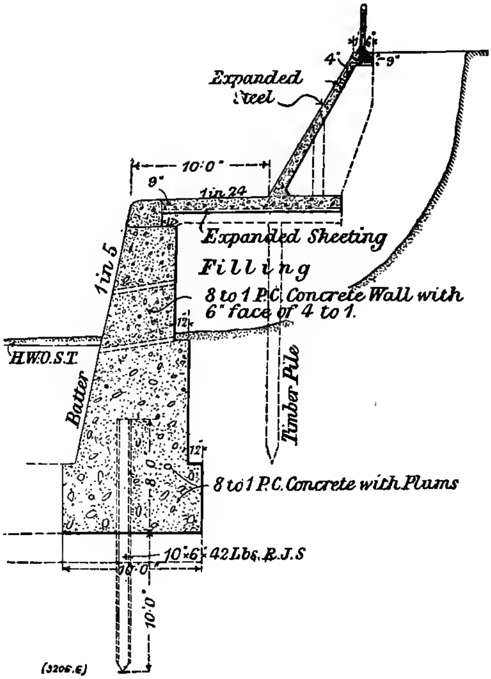


Fig. 70.—New Sea-Wall at Hornsea.

Suggested Reinforced-Concrete and Timber Sea-Defence.—For the protection of a coast-line consisting,

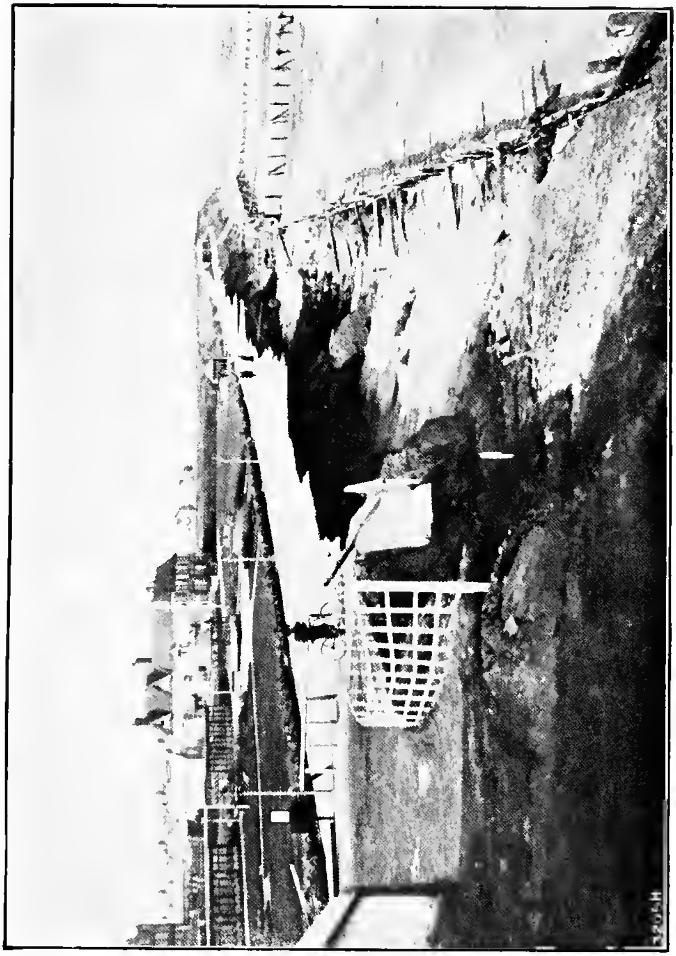


FIG. 71.—OLD SEA-DEFENCES AT HORNSEA, DESTROYED IN 1906 GALES.

[*To face p.* 74.

as does the Holderness coast of Yorkshire, of cliffs of clay surmounted by gravel, an ideal sea-wall would be that shown in fig. 72, but the cost of such a sea-defence would be prohibitive; this would be £27 per lineal yard. The type the author recommends is illustrated in figs. 73 and 74. This design comprises a row of 9-in. by 9-in. pitch-pine piles (creosoted) 17 ft. in length (the length will vary according to circumstances), driven at the foot of the cliff in a line running parallel with the coast-line, the piles being driven at least 10 ft. into the clay, and pitched at 9-ft. centres. 11-in. by 3-in. planking is secured to the outside of this

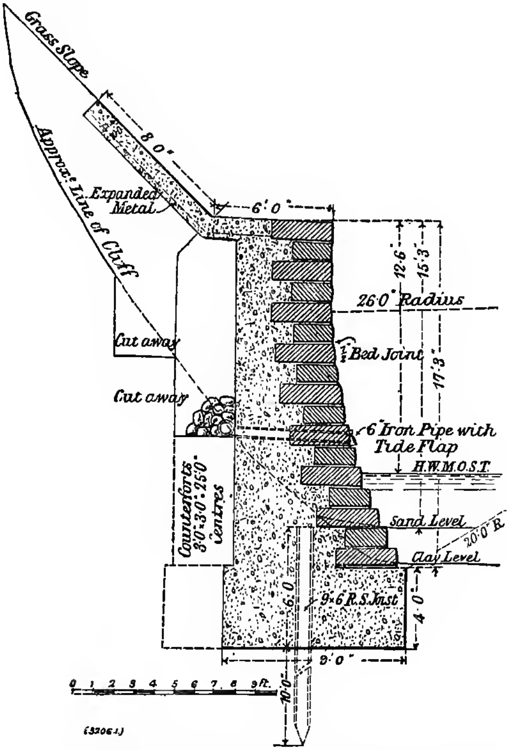


Fig. 72.—Suggested Type of Sea-Wall to Protect Holderness Coast, Yorkshire.

piling by strong 8-in. spikes; the timber is creosoted and so fixed that the bottom plank is inserted entirely below clay level. At the back of the piling a trench is dug, and a mass-concrete wall built as shown. The concrete would be in the proportions of 6 to 1, the base of the wall being well down into the clay, and being 3 ft. 6 in. in width, the top of the wall finishing on a level with the tops of the piles, and being 2 ft. in thickness. This wall, as will be seen, is filled in solid between the piles; the planking thus protecting the face of the sea-wall. At the back of the wall a 4-in. drain is laid, having open joints to receive any drainage from springs in the cliffs; outlets from this drain

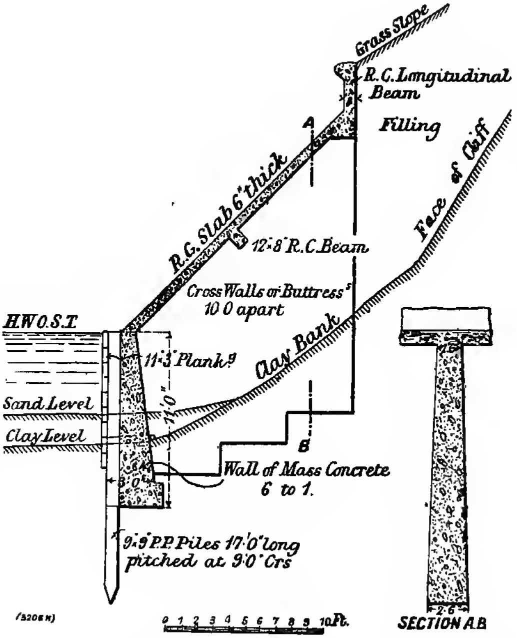


Fig. 73. Fig. 74.

Figs. 73 and 74.—Suggested Reinforced-Concrete Sea-Defence for Holderness Coast.

are carried through the retaining-wall at intervals. Cross-walls, also of 6 to 1 mass concrete, are built every 10 ft.; these are 2 ft. 6 in. in thickness at the base and 1 ft. 6 in. at the top, as shown in section A B, fig. 74. The object of these cross-walls is threefold, namely :—

(*a*) To act as buttresses to the front wall.

(*b*) To carry the reinforced-concrete slab forming the slope, and the beam at the top of same.

(*c*) To divide the sea-defence up into bays or sections, so that should the sea during a severe storm break in at any part, only that section would be damaged. It is always an advantage to divide a sea-defence up into bays in this manner, as serious damage to the structure can seldom then occur, but the cost of dividing up into bays usually prohibits this method being adopted. The foundations for these cross-walls should be stepped up, as shown, to suit the batter of the clay bank.

A reinforced-concrete slab is formed to suit the batter of the cliff. This slab may be of any approved system of reinforcement, care being taken that the bars or other reinforcing steel are inserted well down into the mass-concrete wall at the foot of the slope. The slab may be 6 in. in thickness, and stiffened by the insertion of a reinforced-concrete beam supporting the slab midway. At the top of the slab, and supporting it, a longitudinal beam is built in place; this is supported by the cross-walls already referred to. The beam is 8 in. in thickness, and upon it a reinforced-concrete wall of not more than, say, 5 ft. in height, is built as shown. It may in some cases be necessary to protect the battered cliff above this wall by concreting the face for a height of 10 ft. or 15 ft. A sea-defence of this type, with slight modifications, would be suitable for almost any coast, and the cost would be considerably less than that of the ordinary type of sea-wall. It is necessary to leave expansion joints in the walls and slab. These may be filled with asphalt.

Reinforced-Concrete Sea-Wall at Folkestone.—Figs. 75 and 76 illustrate sections through the reinforced-concrete sea-wall, built in 1910–11, to protect the Earl of Radnor's estate at Folkestone. Fig. 75, which is an elevation of the wall, shows clearly the arrangement of the reinforcement. This is a very interesting piece of work, and the design is somewhat unusual. It gives a good idea, however, of what may be done in reinforced concrete. The reinforcement consists chiefly of $\frac{1}{2}$-in. and $\frac{5}{8}$-in. bars. The face of the wall has a batter of 1 in 6, and the reinforced-concrete wall is protected by a wall of Kentish rag-

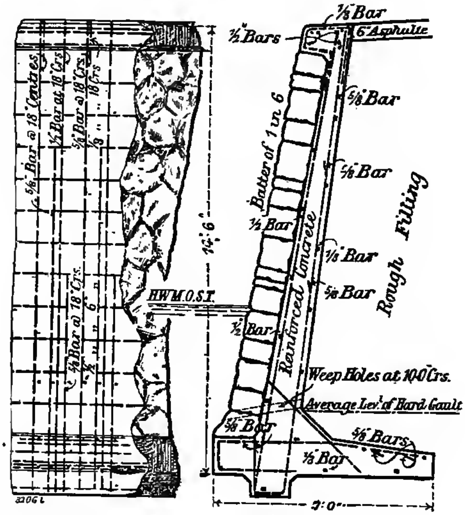


Fig. 75. Fig. 76.

Figs. 75 and 76.—Sea-Wall at Folkestone.

stone, as shown in the section. It will be noticed that high-water of ordinary spring tides rises about 4 ft. up the wall. This design would probably have been improved if buttresses or counterforts had been inserted every 10 ft. The foundation slab is well arranged to prevent sliding forward, owing to pressure behind the wall, and the force acting at its base in front. This is a method to be recommended where reinforced and other walls have a tendency to slide forward. The total height of the wall is 14 ft. 6 in. above the bottom of the foundation slab, and the design is certainly an economic one. Six to one concrete instead of 6 in. of asphalt would have been preferable for the covering of the walk at the back of the wall. It is interesting to note that the whole of this work was carried out by the estate staff. The length of this wall is 1361 lineal feet.

Reinforced-Concrete Piles and Loose Slabs.—It has been suggested that reinforced-concrete piles and slabs fitting into rebates would form an admirable method of construction of a sea-wall. This method is very efficient for the erection of retaining-walls, especially in wet ground, and much useful work on these lines has been carried out. The objections to this method of construction for sea-defence works are: (1) That in driving the piles it is most difficult to get them in precisely their right positions and always exactly plumb, and if they fail in either of these respects, there is a difficulty at once in inserting the vertical slabs. (2) The slabs are somewhat awkward things to handle owing to their weight. A simple reinforced-concrete slab forming the decking is preferable—that is, provided expansion joints are inserted at frequent intervals. (3) Unless the decking slabs are grooved in some way, water gets through the joints, and settlement of the filling at the back of the wall occurs.

Reinforced-concrete groynes will be dealt with in a subsequent chapter.

CHAPTER VII.

OTHER TYPES OF PROTECTION BY SEA-WALLS.

It is proposed to discuss in this chapter various other types of sea-defences, and the first to be dealt with will be sloping and vertical-face sea-walls.

Sloping and Vertical-Face Sea-Walls.—Sea-walls of these types are the most common. The principal advantage of vertical walls is that they are economic in construction, the materials being placed to their greatest advantage. Almost invariably, however, walls of this type and sloping-face walls cost a great deal in the end, for they are usually provided with an apron, which is a costly addition, whereas in a stepped-face wall there is generally no need for this expenditure. The conditions of a harbour wall in deep water are altogether different from those of a sea-wall, which runs parallel with the coast; and experiments as to the relative advantage of battered and vertical walls for harbour purposes form no guide in the case of sea-walls. It is sufficient here to point out that the dead blow from a wave is more likely to result in damage to the structure when striking a vertical wall than when meeting a sloping-faced wall. Further, after the impact the wave falls at the toe of the wall, causing considerable scour, and dredging out the materials from in front of the foundations—that is, if the wall has no apron. Walls have even collapsed as a result of this scouring action. Where it is necessary to construct an apron at the base of a wall, scour at the toe of the apron may usually be avoided by the employment of a timber slope, as shown in fig. 77. In the particular example there illustrated the toe is also protected by 11-in. by 4-in. sheet-piling. Faggots may also be used to form an apron to prevent scouring by the sea at the base of a sea-wall. They may also be employed to prevent the inroads of the sea where there is no permanent sea-defence. They are very economic as regards cost, and often prove most effective. In referring now to battered walls, walls with a batter of not less than 1 in 4 are here intended.

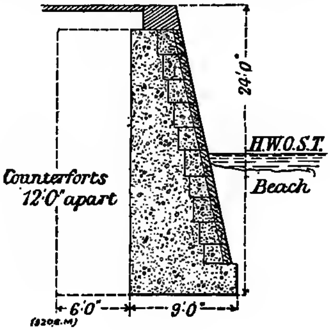


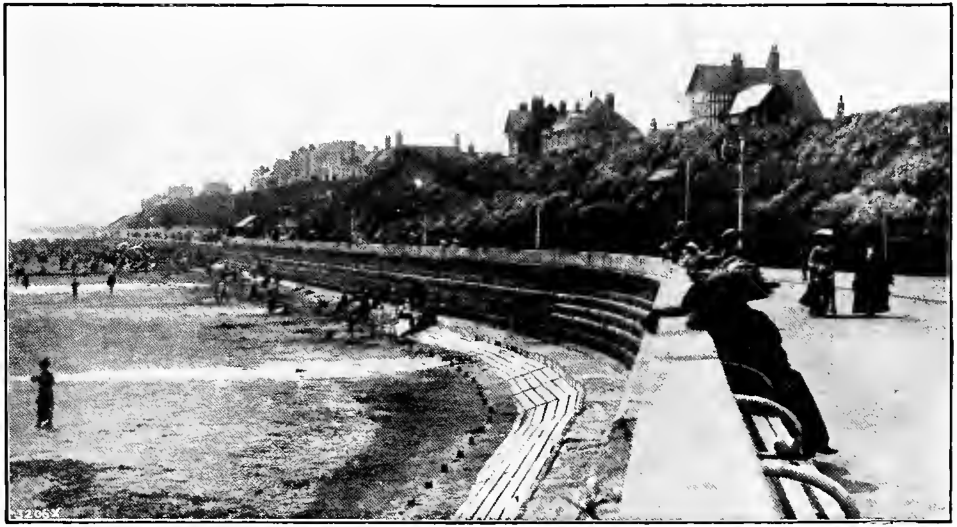
FIG. 78.

In order of merit the various types of sea-walls may be placed as follows :—

1. Stepped-face.
2. Curved-face.
3. Sloping-face.
4. Vertical wall.

One or two examples of sea-walls of the sloping and vertical types will now be described.

Hove.—An illustration of a good wall of the battered



[Spurr & Son, Photographers.

FIG. 77.—PROTECTION OF TOE OF APRON BY TIMBERED SLOPE, BRIDLINGTON

type is given in fig. 78, which represents a sea-wall constructed at Hove. This wall is 9 ft. in thickness at the base and 4 ft. at the top ; it has a batter of 1 in 4. The height of the wall is 24 ft., and counterforts are placed every 12 ft. apart. The wall is faced with concrete blocks, and these are faced with flints. It is surmounted by a stone coping.

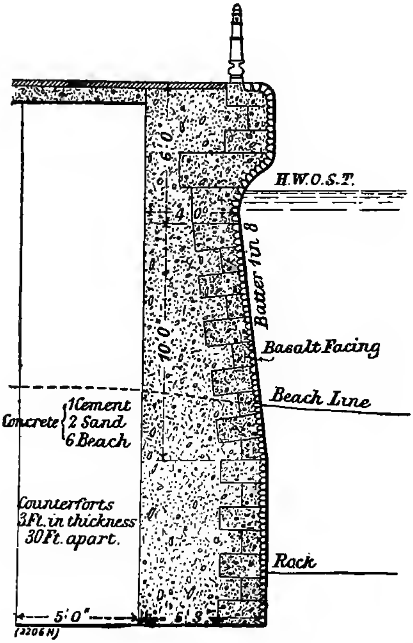


Fig. 79.—Sea-Wall at Caroline Place, Hastings.

Hastings.—The new sea-wall at Caroline Place, Hastings, is another excellent example of a battered-face wall. This was designed and constructed by Mr Philip H. Palmer, M. Inst. C.E., the borough engineer. The structure is clearly illustrated in figs. 79 and 80, and, it will be seen, consists of a sloping-face sea-wall, faced with concrete blocks, which have basalt facing. It has a batter of 1 in 8, and the blocks are backed by 8 to 1 concrete

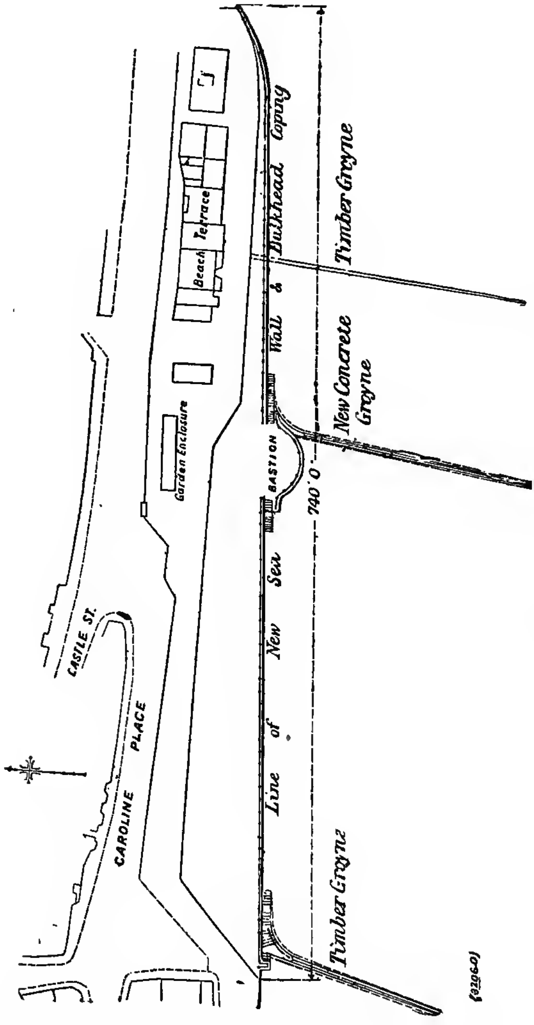
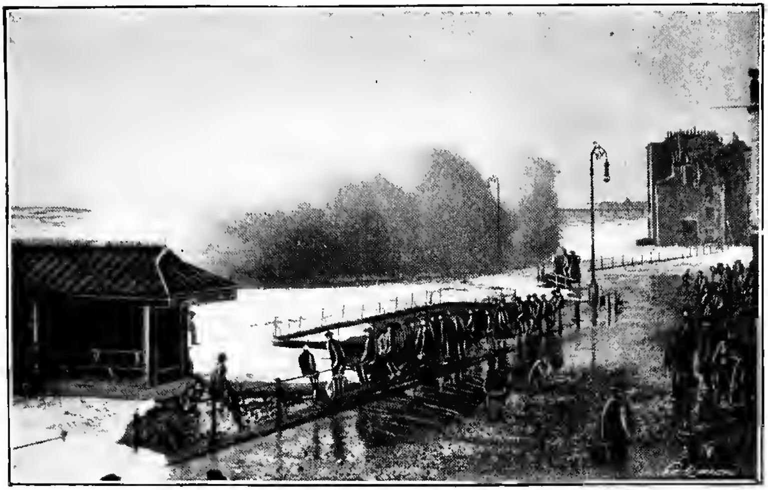


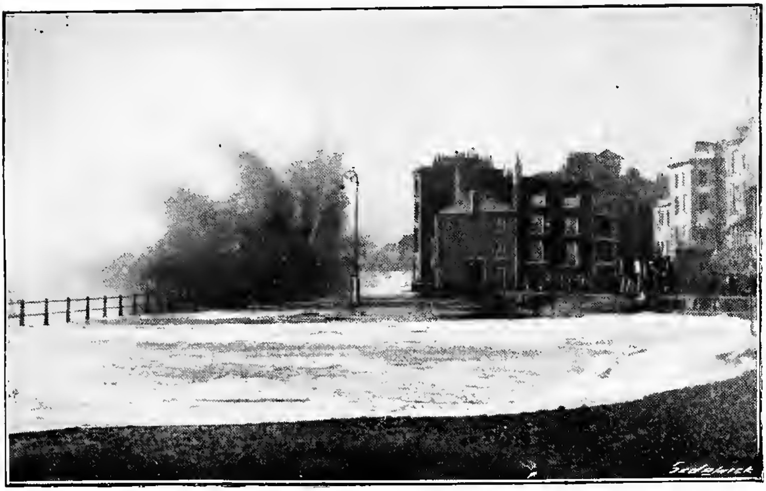
Fig. 80.—Sea-Wall at Caroline Place, Hastings.

of the following proportions: 1 cement, 2 sand, 6 beach. Counterforts 3 ft. in thickness and 5 ft. in width are built 30 ft. apart. The thickness of the wall at its base is 5 ft. 3 in., and at the top 4 ft.; this is remarkably light, con-



[*Forster, Photographer.*

FIG. 81.—STORM WAVE AT HASTINGS; MARCH 1911.



[*Forster, Photographer.*

FIG. 82.—STORM WAVE AT HASTINGS; MARCH 1911.

sidering the exposed situation, but the counterforts of course add considerably to its strength. It is exceptionally well built. The base of the wall is carried 2 ft. below bed rock, and splendid provision is made for throwing back the wave after it has struck the wall. The bull-nosed coping is a most useful arrangement; this principle has been advocated in an earlier chapter. The concrete foundation for the flags at the back of the wall is also satisfactory, as is the construction of a bastion of the shape shown in fig. 80 at the east end of the new wall; this prevents, to some extent, waves racing along the wall, with the consequent scouring effect already referred to. Flights of steps have been built where shown.

Several severe storms have occurred since the erection of this wall. Illustrations of one are given in figs. 81 and 82. This took place in March 1911, while fig. 83 shows a huge storm-wave striking this sea-defence in October 1911. No damage worth speaking of occurred to the wall during either of these storms. The drawings illustrating this work are reproduced by the courtesy of Mr Palmer. The cost of this improvement was £5026.

Projecting Cornice.—The remarks made in a previous chapter regarding the necessity of a projecting cornice apply equally to walls of the sloping and vertical-face type; in fact, they are still more applicable, since, owing to the more upright face of the wall, there is a tendency for the wave to shoot up after impact. Mr P. H. Palmer has considerably improved many of the old sea-walls at Hastings by the pulling down of their upper portion, and adding to them a fairly heavy cornice (see fig. 84). This has had a most beneficial effect, for whereas formerly the promenade at the back of these walls was extremely wet during a south-west gale, now little, if any, water comes over the walls on the sea-front.

Cliff Protection.—A landowner will sometimes adopt what may be termed a "rough and ready" method of protection. The sea has to be kept back, and the landowner's chief concern is naturally to do this at as little cost as possible, quite irrespective of uniformity of design or neatness of appearance. Many strange kinds of sea-defence works are to be found around our coasts in consequence. One example only need be given. It occurs at Bridlington, on the south shore, and is shown in fig. 85. This wall has answered its purpose fairly well, but at times has required considerable repairs. A well-built wall would have cost practically nothing in upkeep. In fairness, however, to the builders, Messrs. Whitaker Brothers, it should be stated that the New Spa sea-wall, which adjoins the wall shown, and which was also built by them, is a very creditable structure, being an exceedingly well-built wall.

COMBINED TIMBER AND RUBBLE SEA-WALLS.

Sewerby Sea-Defence, Bridlington.—Having now dealt with the characteristics of sea-walls of reinforced and plain concrete, protection by timber and rubble will be considered. An example of such construction is to be found at Bridlington. In figs. 86, 87, and 88 a useful structure of the combined timber and rubble type of protection is illustrated. This was constructed at Bridlington; the full length of this sea-defence is 305 yards. It was designed by Mr R. R. Brown, formerly borough engineer, and constructed in 1896 at a cost of £3000, or

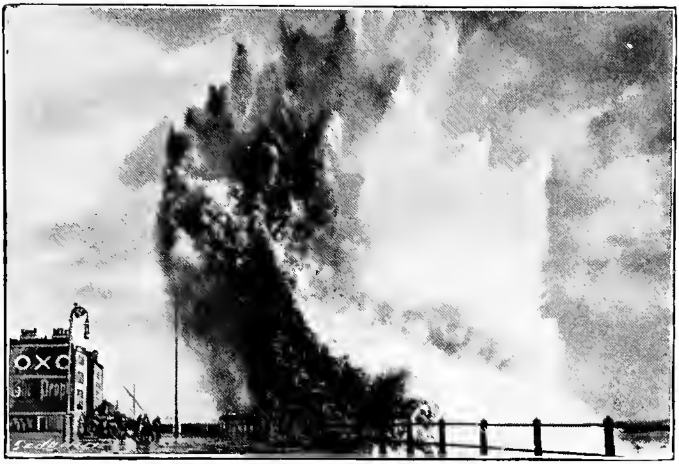


FIG. 83.—STORM WAVE AT HASTINGS; OCTOBER 1911.

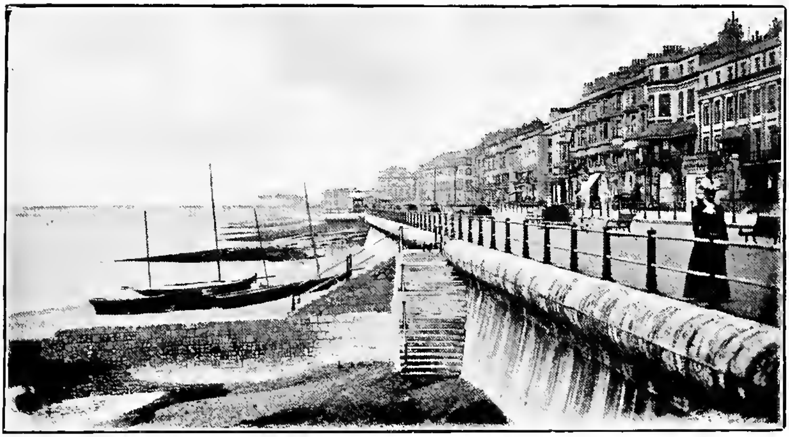


FIG. 84.—PROJECTING CORNICE ON HASTINGS SEA-WALL.

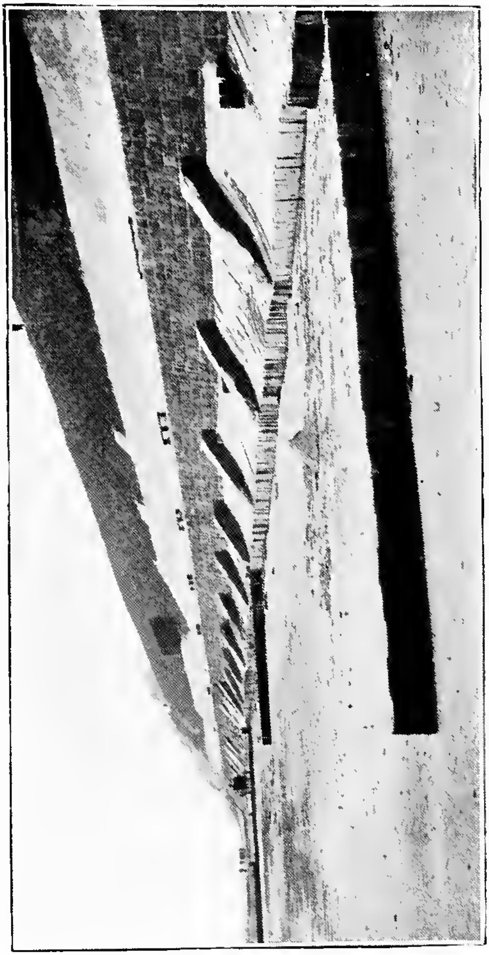


FIG. 85.—CLIFF PROTECTION AT BRIDLINGTON; SOUTH SHORE.

£9, 16s. 8d. per lineal yard. The author was called upon to lengthen this sea-defence in 1899 to the extent of 82 yards; this was done at a cost of £788, or £9, 7s. 4d. per lineal yard. The original design was somewhat improved on in this extension, and the cost of repairs to the added portion have been practically nil; the only expenses incurred have been in replacing small quantities of the chalk pitching forming the slope above the timbering, some of this occasionally getting washed off during heavy seas.

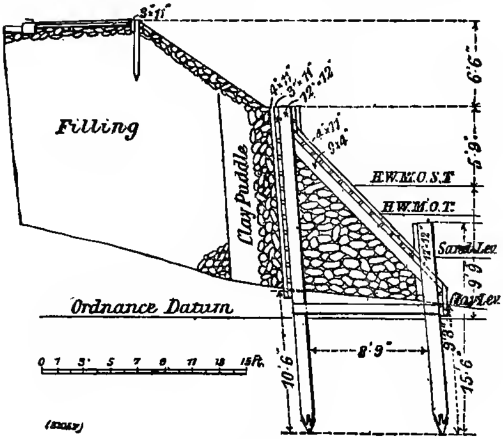


FIG. 86.

The footpath is 21 ft. above clay-level and 18 ft. above sand-level. The top of the back piles is 14 ft. above clay-level, 11 ft. above sand-level, and 9 ft. above high-water of spring tides. The actual construction of these sea-defences may be briefly described as follows: They have two rows of pitch-pine piles, 12 in. by 12 in., placed 10 ft. apart, centre to centre. The back piles are 23 ft. in length, and are driven 10 ft. into the boulder-clay; the front piles, which are pitched 9 ft. in front of the back piles, are 15 ft. in length and are driven 9 ft. into the clay. A tie, 9 in.

by 4 in., connects the front and back piles. The face of this sea-defence is formed of planking. The planks, 3 in. by 11 in., are placed 1½ in. apart, and rest upon bearers, 9 in. by 6 in., placed at an angle of 50 deg., to which they are secured by ribs, 4 in. by 11 in. The planking is filled in at the back with block chalk. Above this there is a chalk slope of 1 in 1·67. The back of this sea-defence is formed of horizontal planking, the planks, 4 in. by 11 in., being placed 3 in. apart. This is backed by a clay puddle wall, 2 ft. 6 in. in thickness, and behind this is sand filling. 9-in. and 6-in. sanitary pipes convey the subsoil water from the back of the puddle-wall on to the foreshore. The top of each of the back pipes is covered with a zinc plate. Wrought-iron 18-lb. pile-shoes were used. The planking is of red wood, and all the timber is creosoted. Where economy is of the greatest importance, and appearance quite a secondary consideration, a sea-defence of this type may be constructed. The block chalk pitching might, however, be dispensed with, and the planking continued to the top, as shown in fig. 87. This design is to be recommended, although it adds slightly to the cost. A similar sea-defence may be seen at Filey, and is illustrated in fig. 89.

One advantage of a sea-defence of this kind has still to be mentioned. The timber jetty forms a cushion for the waves to beat upon, much more elastic in character than a masonry sea-wall.

COMBINED TIMBER AND CONCRETE SEA-WALLS.

Sea-Wall on the Earl of Radnor's Estate, Folkestone.—Some very interesting sea-walls have been built at Folke-

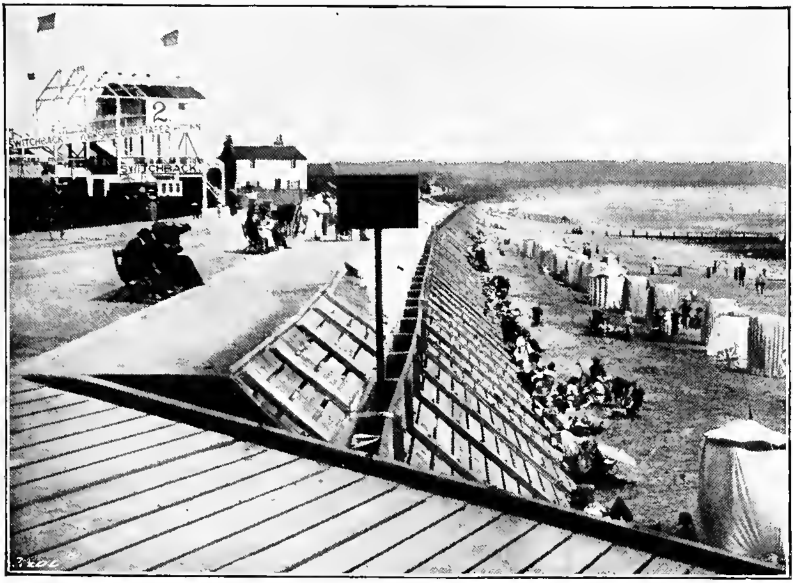
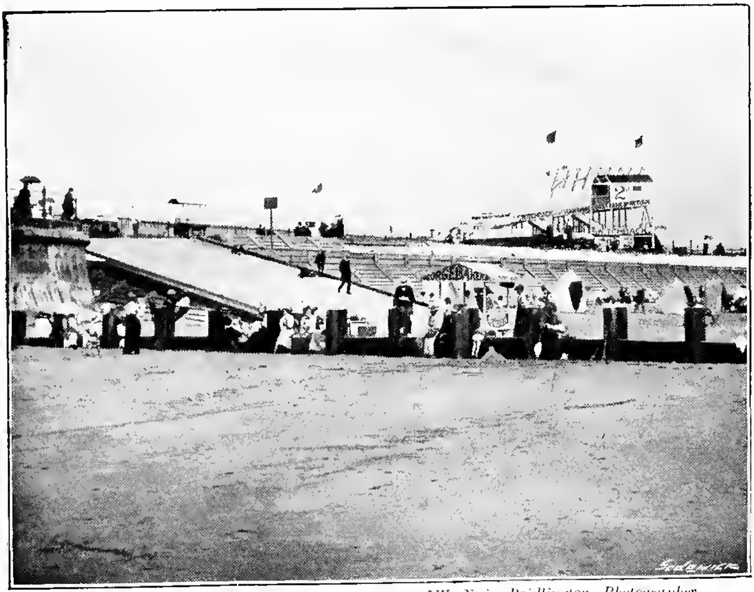


FIG. 87.

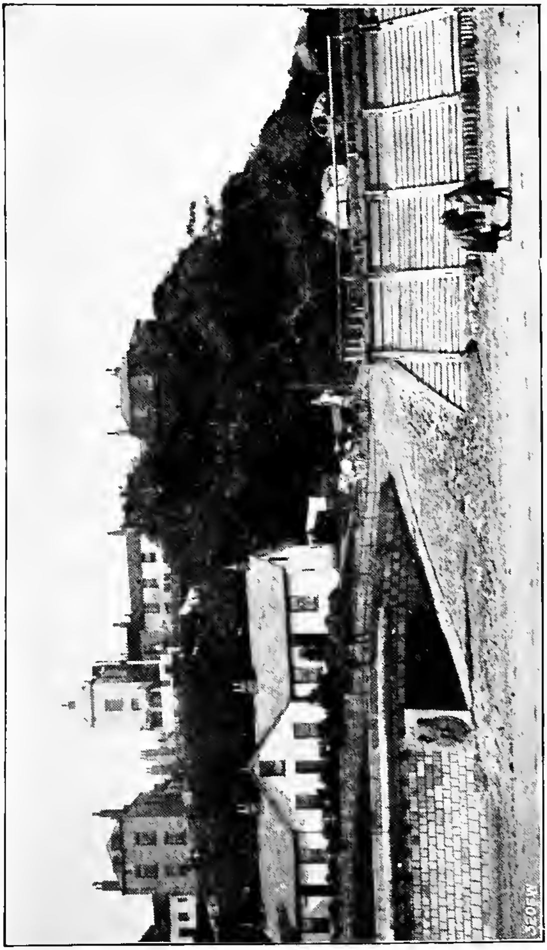


[*W. Nair, Bridlington, Photographer.*

FIG. 88.

FIGS. 87 AND 88.—COMBINED TIMBER AND RUBBLE PROTECTION, BRIDLINGTON.

[*To face p.* 88.



[*W. Fisher, Filey, Photographer.*

FIG. 89.—COMBINED TIMBER AND RUBBLE PROTECTION, FILEY.

stone to protect the estate of the Earl of Radnor. One of these, built of reinforced concrete, has already been described; another is illustrated in fig. 90. This sea-wall was erected in 1905–6, and is 2008 ft. in length. It is constructed of timber with concrete backing. The piles were driven at 5-ft. centres, and the whole of the timber was creosoted. It was originally intended that the backing to the breastwork should be of chalk, but this was afterwards altered to concrete. This wall, of course, needs occasional slight repairs; apart from this it is a very useful type of sea-defence and is answering its purpose well. The wall was built by the estate staff, and reflects great credit upon them and the agent, Mr L. G. A. Collins, who has kindly furnished the particulars here given regarding it. The piles, which are 12 in. by 12 in., were driven in at a batter of 1 in 6, after which 9-in. by 3-in. planking was secured at the back of them. A trench was then formed behind this and filled with 7 to 1 Portland

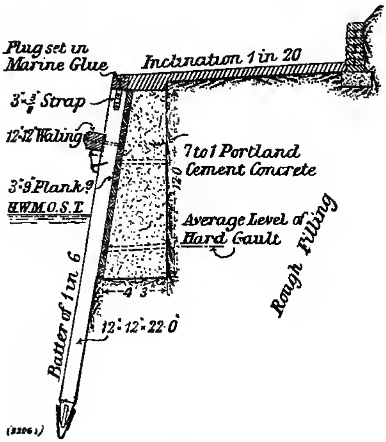


Fig. 90.

cement concrete put in layers not exceeding 18 in. This wall is 4 ft. 3 in. in thickness at the base and 2 ft. 3 in. at the top, and has a vertical back. The foundations are carried well into the hard gault. A 12-in. by 12-in. waling, carried on cleats, has been bolted to the face of the piles, and runs the whole length of the structure. Possibly concrete might have been preferable in the construction of the walk on the top of the wall, and the foundations of the wall might have been carried to a greater depth with advantage.

Natural Protection of Sand-Dunes.—Sand-dunes may be, and often are, protected in England by encouraging the growth of marram-grass. This method of protection may be seen on the Lincolnshire coast and also on the coast of Norfolk. On the banks of the Mersey it may also be found. While this grass has in places had a binding effect upon the sand which forms the dune, such a method of protection is very unreliable. On the Norfolk coast, for example, where the dunes are protected partly by artificial means and partly by marram-grass, the sea is actually encroaching. It should be mentioned, however, that the planting of marram-grass in a systematic manner is not carried out in this country as it is in Holland.

CHAPTER VIII.

THE ACTION OF SEA WATER ON CEMENT AND CONCRETE.

No material is used so extensively in the construction of sea-walls and breakwaters as concrete; and it is therefore of the greatest importance that the reader should have a knowledge of the relative value of using fresh and sea water respectively in the mixing of same, and also of the effect produced by immersing concrete in sea water. It has been almost the general rule in this country in constructing maritime works to use sea water in the mixing of the concrete, but the author does not recommend this, for from experiments carried out by Mr Jas. Watson, M.Sc., and himself, the results of which are set out in this chapter, he is convinced that neat cement is detrimentally affected by being mixed with sea water, and although his experiments show that concrete (3 to 1) is only slightly affected, he thinks that it is well to use fresh water in the mixing of concrete wherever possible.

The subject of the action of sea water on cement has been that upon which many have written. The author would especially refer to the French literature on this subject by Le Chatelier, Deval, Feret, Candlot, Maynard and Villetart; to German works by Dr Michaëlis (*vide* Dr Michaëlis on "The Action of Sea Water upon

Hydraulic Cements," *Minutes of Proceedings, Institution of Civil Engineers,* vol. cxxix.), and also to the reports of the German Association of Cement Manufacturers. Researches dealing with the action of sea water on cement concrete have long been conducted, and there is now a considerable amount of literature on this subject. The reports of the Brussels Congress (1906) of the International Association for Testing Materials give a good idea of the present state of knowledge.

Engineers and others in America have also carried out a large amount of research work in connection with this matter, the latest American literature on it being an article which appeared in *Engineering News* on December 24, 1908, under the title of "Scheme of the Boston Harbour Tests on the Effect of Sea Water on Concrete," and another article published on December 30, 1908, in *Engineering-Contracting* under the title of "Specifications for Test Specimens of Concrete to be Immersed in Sea Water, by the United States Navy Department."

This subject has also been dealt with by British engineers and others from time to time, the latest publications being an article entitled "The Decomposition of Cement by Sea Water," which appeared in the *Quarry* of January 1909, and an interesting and instructive article on the subject by Mr C. J. Potter of Newcastle-on-Tyne, which appeared recently in the *Journal of the Society of Chemical Industry.*

That brings the literature on the subject about up to date.

Before giving particulars of his own experiments the author would give the conclusions arrived at by two well-known authorities on cement after a series of careful tests :—

Candlot (*Céments et Chaux Hydrauliques*) gives some thousands of figures showing that sand briquettes are unaffected, but that neat briquettes decline in strength after about six months when gauged with sea water and immersed in sea water.

(The author's experiments prove the accuracy of the first part of this conclusion.)

Alexandre publishes figures proving that sand briquettes are unaffected by the use of sea water for gauging.

(The author's tests prove this.)

THE AUTHOR'S EXPERIMENTS.

The author first set himself the task of discovering :—

1. The effect produced upon cement and concrete by immersing these materials in fresh and sea water respectively :

(*a*) The tensile strength of briquettes made with neat cement, 20 per cent. of fresh water being added, the briquettes being immersed in *fresh* water for various periods.

(*b*) The tensile strength of similar briquettes kept in air for the same periods.

(*c*) The tensile strength of 3 to 1 (sand and cement) briquettes, subjected to the same conditions as referred to in (*a*).

(*d*) The tensile strength of 3 to 1 briquettes, subjected to the same conditions as referred to in (*b*).

(*e*) The effect of immersing concrete, mixed with fresh water, in sea water for certain periods, as compared with immersing it in fresh water, or keeping it in air for the same periods.

(*f*) The effect of immersing in sea water for various periods concrete mixed with 20 per cent. of sea water, as compared with immersing it in sea water for similar periods when mixed with fresh water.

The cement used in these tests is briefly described as follows :—

Residues.—On a 5776 (76 meshes per lineal inch) sieve = 0·5 per cent. On a 10,000 (100 meshes per lineal inch) sieve = 2·0 per cent. On a 32,400 (180 meshes per lineal inch) sieve = 11·5 per cent.

Specific gravity = 3·112
Flour = 54·5 per cent.
Faija bath test : Pat sound and hard.
Time of set :
Neat (mixed in fresh water) : Initial set = 35 minutes.
Permanent set = 6 hours in a temperature of 60 deg. Fahr.
Percentage of water added : 20.

The chemical analysis was as follows :—

Chemical Analysis.

	Per cent.
Insoluble residue	0·82
Silica	20·43
Alumina	9·10
Oxide of iron	1·95
Lime	62·65
Magnesia	1·25
Sulphuric anhydride	1·38
Loss on ignition	1·66
Alkalies and loss	0·76
	100·00

1. The effect produced upon cement and concrete by immersing these materials in fresh and sea water respectively :—

(*a*) The tensile strength of briquettes made with neat cement, 20 per cent. of fresh water being added, the briquettes being immersed in *fresh* water for various periods.

The author had a large number of briquettes made; half of these were placed in water after a twenty-four hours' set, and kept in water for five days, the temperature of water being 60 deg. Fahr. ; the remainder were kept in air for the seven days at a temperature of 60 deg. Fahr., the result being :—

Tensile strength of briquettes placed in fresh water after a twenty-four hours' set :

Average.

7 days' test =685 lb. per square inch.
14 ,, ,, =787 ,, ,, ,,
28 ,, ,, =875 ,, ,, ,,

(*b*) The tensile strength of similar briquettes kept in air for the same periods :—

Tensile strength of those kept in air :

Average.

7 days' test =443 lb. per square inch.
14 ,, ,, =525 ,, ,, ,,
28 ,, ,, =775 ,, ,, ,,

(*c*) The tensile strength of 3 to 1 (sand and cement) briquettes, subjected to the same conditions as referred to in (*a*) :—

Tensile strength of 3 to 1 briquettes immersed in fresh water after a twenty-four hours' set :

Average.

7 days' test = 220 lb. per square inch.
14 ,, ,, = 250 ,, ,, ,,
28 ,, ,, = 322 ,, ,, ,,

(*d*) The tensile strength of 3 to 1 briquettes, subjected to the same conditions as referred to in (*b*) :—

Average.

7 days' test = 200 lb. per square inch.
14 ,, ,, = 277 ,, ,, ,,
28 ,, ,, = 353 ,, ,, ,,

(*e*) The effect of immersing concrete (mixed with fresh water) in sea water for certain periods, as compared with immersing it in fresh water, or keeping it in air for the same period :—

Neat Cement Test.

Period of test.	Neat cement mixed with fresh water and immersed in sea water after 24 hours' set. (lb. per sq. in.)	Neat cement mixed with fresh water and immersed in fresh water after 24 hours' set. (lb. per sq. in.)	Neat cement mixed with fresh water and kept in air. (lb. per sq. in.)
7 days' test =	770	685	443
14 ,, ,, =	742	787	525
28 ,, ,, =	812	875	775

3 to 1 Test.

Period of test.	3 to 1 briquettes mixed with 10 per cent. of fresh water and immersed in sea water after 24 hours' set. (lb. per sq. in.)	3 to 1 mixed with 10 per cent. of fresh water and immersed in fresh water. (lb. per sq. in.)	3 to 1 mixed with 10 per cent. of fresh water, and kept in air.
7 days' test =	242	220	200
14 ,, ,,	278	250	277
28 ,, ,,	360	322	353

(*f*) The effect of immersing in sea water for various periods concrete mixed with 20 per cent. of sea water, as compared with immersing it in sea water for similar periods when mixed with fresh water.

The author had a number of briquettes made with neat cement and 3 to 1 concrete, and these were mixed with sea water and fresh water, and subjected to seven, fourteen, and twenty-eight days' tests, the result being as follows :—

Neat Cement Test.

Period of test.	Neat cement mixed with sea water and immersed in sea water after 24 hours' set. (lb. per sq. in.)	Mixed with fresh water and immersed in sea water after 24 hours' set. (lb. per sq. in.)	Mixed with fresh water and immersed in fresh water after 24 hours' set. (lb. per sq. in.)
7 days' test =	693	770	685
14 ,, ,, =	775	742	787
28 ,, ,, =	773	812	875

3 *to* 1 *Test.*

Period of test.	3 to 1 briquettes mixed with sea water and immersed in sea water after 24 hours' set. (lb. per sq. in.)	Mixed with fresh water and immersed in sea water after 24 hours' set. (lb. per sq. in.)	Mixed with fresh water and immersed in fresh water after 24 hours' set. (lb. per sq. in.)
7 days' test =	180	242	200
14 ,, ,, =	287	278	277
28 ,, ,, =	293	360	353

Neat cement briquettes mixed with sea water and immersed in sea water :—

At 7 days	=597 lb. per square inch.
14 ,,	=775 ,, ,, ,,
28 ,,	=780 ,, ,, ,,
3 months	=730 ,, ,, ,,
6 ,,	=843 ,, ,, ,,
24 ,,	=900 ,, ,, ,,

Using from the same consignment of cement for 3 sand to 1 cement briquettes, there was found a gain of 27 per cent. from the fourteen to twenty-eight days' period when the briquettes were immersed in fresh water. In salt water the gain was only 1 per cent.

CONCLUSIONS.

(1) From the foregoing tests—(*a*), (*b*), (*c*), and (*d*)—the author concludes that neat cement is increased considerably in tensile strength by being kept continuously in fresh or sea water, but that concrete is practically of the same strength when immersed in these as when kept in air.

(2) That the use of sea water in the mixing of neat cement and the immersing of the briquettes in sea water causes a decrease in strength of briquette at seven days over those mixed with fresh water and immersed in sea water, but that at fourteen days the former have the advantage of the latter; between fourteen and twenty-eight days, however, the briquettes mixed with sea water do not gain in strength, while the others do, so that at twenty-eight days those mixed with fresh water are stronger than those mixed with sea water. In the author's experiments the proportion was in the ratio of 812 to 773.

(3) In the case of the 3 to 1 briquettes the same thing takes place, but to a much less extent; the briquettes mixed with sea water do, in this case, increase slightly in tensile strength between the fourteen and twenty-eight days' period. We might regard the sand briquettes as unaffected by the use of sea water, as did Candlot (*Céments et Chaux Hydrauliques*) and Alexandre. They are only slightly affected.

(4) It would appear from these tests that neat cement mixed with sea water and immersed in sea water has not so great a tensile strength at three months after mixing as at fourteen days, but that after the former period it increases in strength, so that at the end of the six months' period it is stronger than it has previously been, and the tensile strength increases for at least two years. This does not coincide with the views expressed by Candlot and previously referred to.

(5) These tests indicate that the detrimental effect produced by the use of sea water in the mixing of con-

crete is neutralised by the insertion of such concrete in fresh water.

2. THE CHEMICAL ACTION UPON CEMENT AND CONCRETE PRODUCED BY MIXING THESE WITH SEA WATER.

(Contributed by Mr James Watson, M.Sc.)

Sea water has the following salts in solution :—

Sodium chloride (salt)	=2·7	per cent.
Magnesium chloride	=0·32	,,
Magnesium sulphate	=0·22	,,
Calcium sulphate	=0·13	,,

The sodium chloride is without action on cement when contained in the gauging water, except perhaps for its power of retarding the solution of the aluminates and silicates of lime (which forms one of the processes of setting), and thus delaying the setting for a few hours.

The other constituents of sea water, with the exception of magnesium chloride, are already present in cement, and the slight addition of magnesia and sulphuric anhydride brought about by the use of sea water for gauging is not worth consideration. From the theoretical point of view, then, one would not expect the use of sea water for gauging to be attended with any unsatisfactory results, and a large number of practical tests have been published which support this conclusion. During recent years, however, opinions in this matter have changed; the latest elaborate tests which have been made indicate clearly that sea water *has* a destructive action upon Portland cement concrete, caused by the dissolution of hydrate of lime (of which a set cement contains about 40 per cent.) and the subsequent deposition in the interior of the mass of a sulpho-aluminate of lime which expands and causes disruption.

With a dense concrete of well-proportioned aggregate the rate of solution of the hydrate of lime is slow, and it is stated that the action is not appreciable for five or six years, but that disintegration may be complete in twenty years.

A porous concrete, or concrete containing cracks, will allow ready ingress of sea water, and disintegration will then be more rapid.

How to allay the Destructive Action of Sea Water.—There are two means by which the destructive action on concrete of sea water may be delayed, although not entirely prevented :—

(1) By preserving the concrete in air for several months, in order that by absorption of carbonic anhydride from the air the hydrate of lime may become carbonated, and thus rendered insoluble.

This remedy of course could not possibly be adopted in most of the works where concrete is mixed with sea water, such as harbour works, foreshore protection works, etc.

(2) By mixing puzzuolanic materials with the cement some of the hydrate of lime is taken into combination with the silica and alumina, and solution is prevented.

Although the solution of the hydrate of lime in the concrete renders the latter porous, and weakens it to a certain extent, it is the expansion of the sulpho-aluminate of lime which causes most damage, and cements have accordingly been produced in which alumina was absent, its place being taken by oxide of iron. Such cements behave much better in the presence of sea water, but it is impossible to state yet whether they are indestructible.

The action of sea water upon concrete just described by the author seems incredible in face of the numerous examples of harbour walls, docks and sea-walls, which have withstood the action of the waves for several decades, and yet still appear to be in good condition; it is quite possible of course for the exterior of these masses of concrete to be in a good state of preservation, and for a thorough investigation of the inside to reveal alarming cavities and fissures caused by the chemical action upon the concrete set up by the sea water.

When concrete is mixed with *fresh* water and immersed in sea water a chemical action is undoubtedly going on, but to a much less degree than when mixed with sea water and immersed in sea water.

The author, in conclusion, would say that sea water should, in his opinion, never be used when it is possible to use fresh; he has always insisted on the use of *fresh* water in the mixing of concrete for any sea-walls or similar works which he has carried out. Fine sand should also be avoided in the mixing of concrete for sea works, otherwise the sea water will filter into the concrete, and have an injurious effect upon it. He would acknowledge his indebtedness to Mr A. C. Davis, managing director to the Saxon Portland Cement Company, and to Mr James Watson, M.Sc., for much valuable information on this important subject.

CHAPTER IX.

GROYNES.

THE protection of coasts by sea-walls alone, whether of masonry or timber construction, is not sufficient. In addition an efficient system of groyning is necessary, and groynes form a necessary complement to sea-walls. Their purpose is to raise the beach level by the accumulation of shingle. Whether high or low, short or long, they tend to retard the travel of shingle along a coast. It naturally follows that the higher the groyne the greater the accumulation on the windward side; also, that the further seaward the groyne is carried the more effective it will be, as shingle will not then escape around its extremity. To build a sea-wall first, and thus set up scour, and subsequently to build groynes, is putting the cart before the horse; the groynes should be erected first. A uniform pattern, suitable for all foreshores, is an impossibility. A high groyne may be most effective on one foreshore, a low one on another. What would be entirely successful on the East Coast might be unsuitable for the South. There are four types of groyne construction in this country—viz. timber, concrete-block, reinforced-concrete, chain-cable.

TIMBER GROYNES.

Timber groynes may be divided into (1) high timber groynes; (2) low timber groynes.

High Timber Groynes.—Good examples of high timber groynes may be seen at Cromer on the East Coast, and at Hastings, Eastbourne, and Folkestone on the South. Figs. 91 and 92 illustrate one of the groynes at Eastbourne. This type of groyne is not altogether satisfactory, for the following reasons: (*a*) The beach is raised to a considerable height on the windward side, while on the leeward side there is very little shingle. This is well illustrated in fig. 95, which represents the lee side of a high timber groyne at Eastbourne, taken after a storm. Groynes of this type have frequently to be lowered for this reason; (*b*) they are unsightly; (*c*) dangerous to children using the foreshore during the summer months; (*d*) costly to construct and expensive to maintain; (*e*) they cannot be raised gradually as the beach accumulates; (*f*) owing to the scarcity of shingle or sand on the leeward side, and the consequent greater depth of water, wave-action is more severe, and erosion frequently occurs on that side, while high-water mark is driven back on the windward side; (*g*) the large land-ties standing up above the foreshore tend to create a scour.

Eastbourne faces south-east, and the sea-defence works of this town consist of about two miles of sea-walls and 74 timber groynes; seven additional groynes protect the outfall of the Commissioners of Pevensey Levels. Many of the groynes are of the old-fashioned high timber type, to which reference has been made above, but some

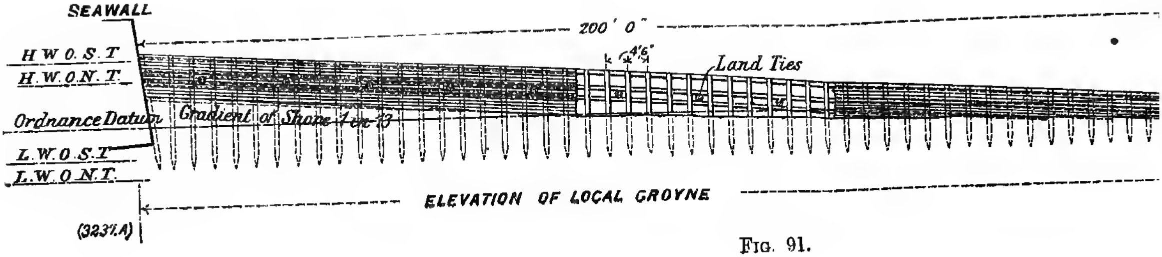


FIG. 91.

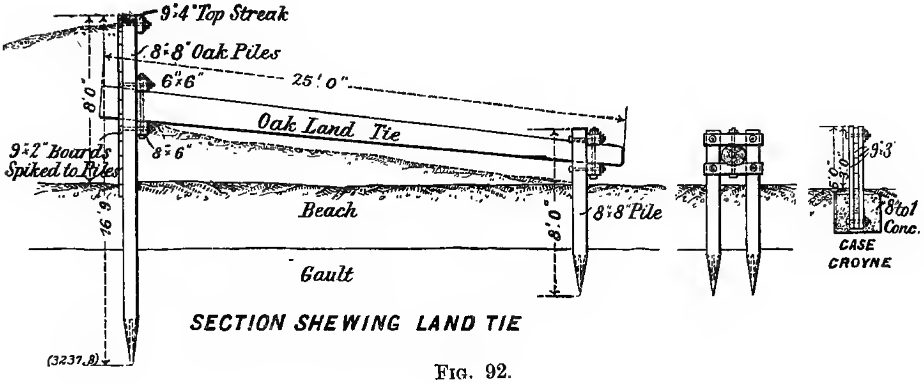
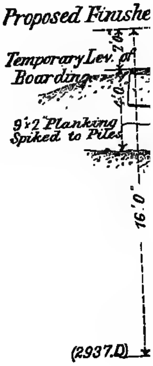


FIG. 92.



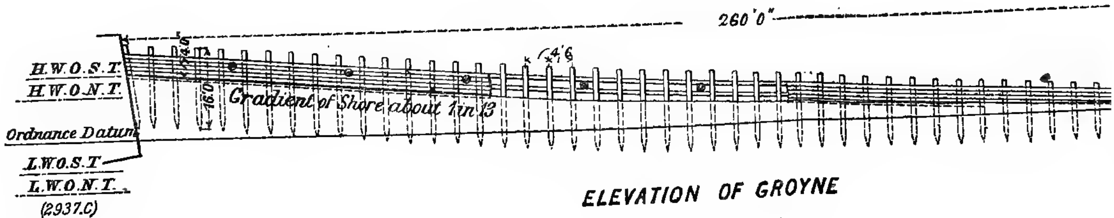
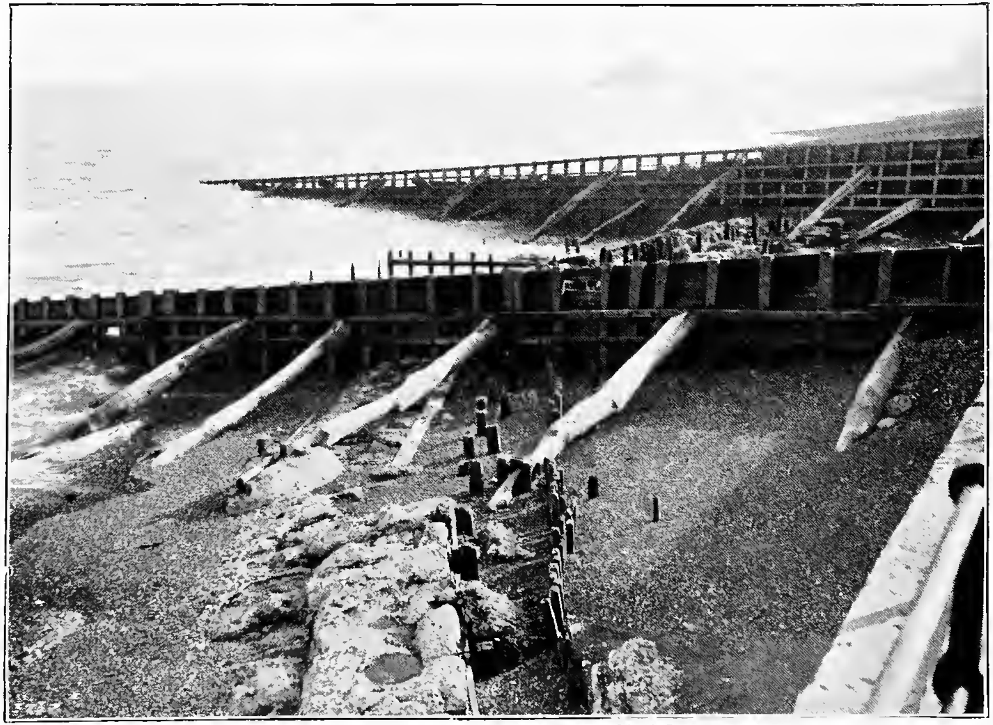


FIG. 94.



[*G. & R. Lavis, Eastbourne, Photographers.*

FIG. 95.—DETAILS OF GROYNES AT EASTBOURNE.

of these have been improved considerably by the present borough engineer, Mr A. E. Prescott. Previous to these alterations the sea was advancing upon the land, causing considerable alarm. The travel of beach on this coast is from west to east, the range of the tides being 22 ft. 10 in. spring tides, and 15 ft. neap tides. The prevailing wind is south-west. A south-west gale occurring at the time of spring tides causes the heaviest seas.

The Eastbourne groynes, illustrated in figs. 93 and 94, are of the following construction: 9 in. by 9 in. pitch-pine and oak piles, varying in length from 14 ft., with iron pile-shoes, are driven into the foreshore bottom underlying the shingle to a depth of about 9 ft. They are set 4 ft. 6 in. apart, centre to centre, with walings 8 in. by 6 in. and 6 in. by 6 in. Planks 9 in. by 2 in. are spiked to the piles in lengths of 20 ft. and over, so as to span four bays and break joint. Large oak land-ties are fixed at right angles to the piles. When erected these groynes were laid to the contour of the foreshore, and extended from beyond high-water mark, where possible, well towards low-water mark, an average length of 300 ft. They are at right angles to the foreshore, and on an average about 70 yards apart. The majority of them are high groynes, and when originally constructed varied from 8 ft. to 10 ft. high at the shore end, and about 4 ft. at the low end, and did not extend to low-water mark. Large quantities of beach collected on the windward side, but in some instances there was a difference of 6 ft. to 8 ft. in the level on the leeward side. In order to avoid this unequal building up the groynes have been scuttled where necessary—*i.e.* the height has been reduced by dispensing with 2 ft. or 3 ft. of continuous boarding in order to allow the beach to pass through to the other side, and low groynes were continued from the ends of the old groynes to low-water mark. The height of the more recently constructed groynes varied from 4 ft. at the land end to about 2 ft. at low-water mark.

In the year 1886 the central wall to the west of the pier at Eastbourne had its face exposed 8 ft. vertically from the coping for a considerable distance. After the erection of the groynes the beach gradually accumulated, and at the present time it is level with the lower parade. To the east of the pier, about the same date, the sea-wall then completed was exposed vertically to a depth of 18 ft. to 20 ft. The shingle is now level in some places with the coping. Seven Case groynes were erected to the east of the pier in 1897. Most of these were continued from the toe of the old high groynes, as shown in fig. 91, and extended to low-water mark. These have been most successful in accumulating the sand and raising the shore level. As the sand accumulated, the groynes have been raised by adding more planks, and most of them are now only just visible above the sand. The cost of the Eastbourne groynes may be taken as follows: One of the ordinary groynes, 100 yards long, costs £375, or 25s. per lineal foot; the Case groynes, 100 yards long, cost £68, 15s., or 4s. 7d. per lineal foot.

At Folkestone the Earl of Radnor has erected eighteen groynes. Thirteen of these are as shown in figs. 96 and 97, while five are of the old type with iron piles. The type of groyne shown in fig. 96 was formerly used; since 1907 that shown in fig. 97 has been adopted; the only difference between the two types is in the bracing and key-pieces. The newer pattern is the cheaper to build. Six or seven braces are fixed to each groyne and are placed on every fourth pile. A waling-piece runs for about 100 ft. down the groyne. Piles are driven at 4-ft. centres. The two top planks are fixed with coach-screws ; this has been found most convenient for removal or replacing according to the level of the beach. At the sea-end of some of the longer groynes sea-worms have necessitated occasional repairs,

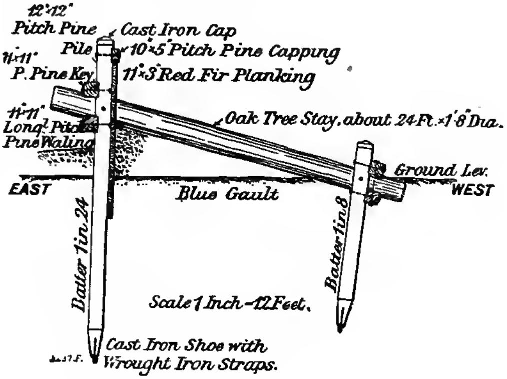


FIG. 96.

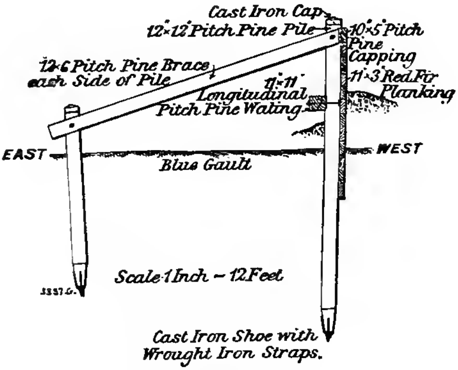

Cast Iron Cap
12"×12" Pitch Pine Pile
10"×5" Pitch Pine Capping
11"×3" Red Fir Planking
12"×6" Pitch Pine Brace each Side of Pile
11"×11" Longitudinal Pitch Pine Waling
EAST
WEST
Blue Gault
Scale 1 Inch – 12 Feet
3337 G.
Cast Iron Shoe with Wrought Iron Straps.

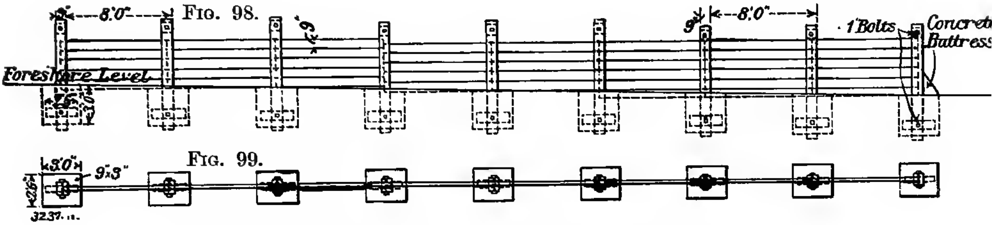
FIG. 97.

FIGS. 96 AND 97.—GROYNES AT FOLKESTONE.

but the upkeep so far has not been excessive. These groynes are easier to repair than the old type with iron piles. The first cost is certainly greater, but this is more than made up for by the difference in length of life of the two types and the facility with which repairs may be executed.

Low Timber Groynes.—There are various types of low timber groynes, one of the most effective being the Case groyne. This groyne is the invention of Mr Edward Case, who first put down groynes of this type at Dymchurch in 1894. Similar groynes have now been erected in many places around our coasts, and they are to be strongly recommended. Their chief advantages are: (*a*) That they can be adapted to any foreshore, whether flat or steep; (*b*) they can be erected very expeditiously; (*c*) are economical; (*d*) no special plant or skilled labour is required in their construction; (*e*) they can be built up as the beach accumulates; (*f*) they cost practically nothing in maintenance. This type should in every case be continued to low-water mark of spring tides. They should be not more than 2 ft. in height above the foreshore level when first put down. The system is extremely simple and very effective, as is proved from the results obtained at Dymchurch, Southwold, Deal, Eastbourne, Morecambe, Lowestoft, Sheringham, and many other places. The short Case groynes constructed by Mr Prescott at the ends of the high groynes at Eastbourne are shown in fig. 91, and may be briefly described as follows: Pairs of piles are spaced at 7-ft. 6-in. centres; they are of 9-in. by 3-in. pitch-pine, and have 9-in. by 3-in. planking inserted between them. The feet of the piles are secured by being embedded in a large block of 8 to 1 cement concrete. The piles have usually sole key-pieces about 18 in. long at the bottom embedded in the concrete block. The groynes erected at Dymchurch are twenty in number, and vary in length from 300 ft. to over 1000 ft. They have resulted in the accumulation of large quantities of sand.

The disadvantage of this system, if there be one, is that the work of constructing a groyne of this type is a lengthy process. It is impossible to know for some considerable time what the groyne is actually going to cost.



Figs. 98 and 99.—The Case Type Groynes at Morecambe.

Figs. 98 and 99 represent one of a number of groynes of the Case type erected at Morecambe. The special feature about these is the addition of concrete buttresses, which, it is claimed, are very useful. Four Case groynes were put down upon the foreshore at Blackpool, at the north end of the borough, in 1898–99. They are about 500 yards in length, and spaced about 70 yards apart, and at right angles to the foreshore. It is understood that in this instance their erection has had little or no influence on the conditions of the foreshore, either favourable or unfavourable. It is desirable in some cases to extend Case groynes below low-water mark; in this connection it may be remarked that excellent results have been obtained at Weymouth by putting down the Case submerged groynes. It is not advisable to construct such groynes in a greater depth of water than 3 ft., the cost of doing so being very heavy, and the results not being commensurate with the additional expenditure.

CHAPTER X.

GROYNES—(*continued*).

Low Timber Groynes (*continued*).—The foreshore and sea-walls at Bridlington, north of the harbour, are protected by a system of groynes. Low-water mark on this side of the harbour is 250 yards further seawards than

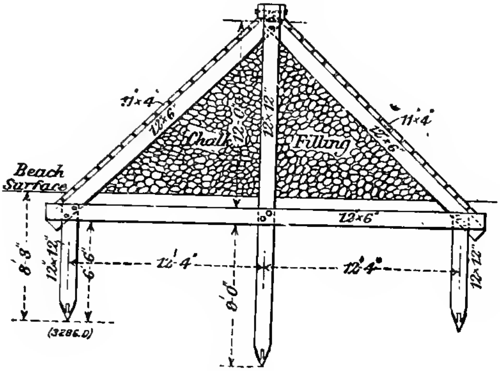
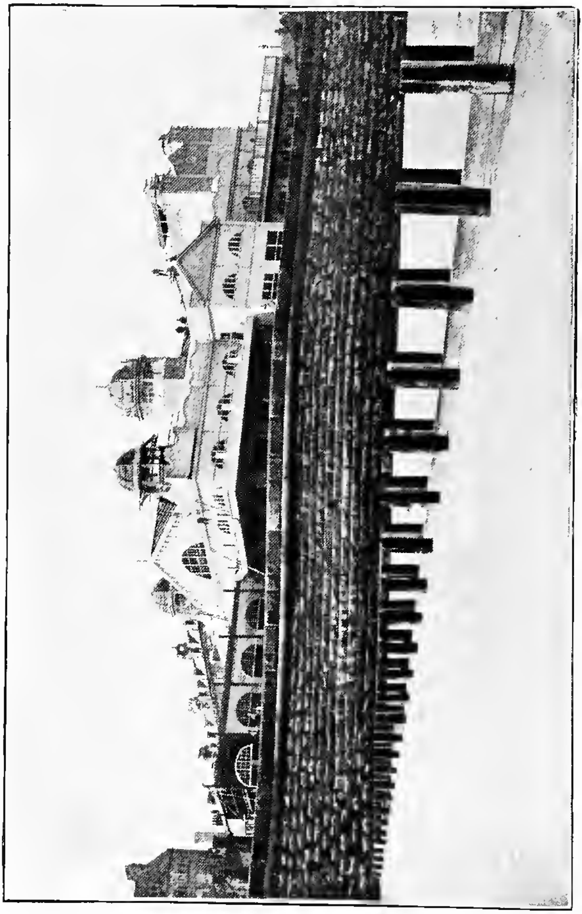


Fig. 100.

on the south side, due to the harbour projection, which traps the shingle as it travels in a southerly direction. The first groynes erected on the north foreshore were five heavy timber groynes, A-shaped, constructed in 1868; two of these, illustrated in fig. 100, are still in existence; the other three lasted 29, 30, and 35 years. The two existing groynes are 135 ft. and 122 ft. in length respectively; they are 140 yards apart, and at right angles to the shore. Their height above shore at highest part of groyne, is 12 ft.; at the lowest part (seawards end), 3 ft. They consist of 12-in. by 12-in. piles, spaced at 9-ft. centres, and A-shaped frames, planked over, with block chalk filling, the sides being at an angle of 35 deg.

The planking consists of 11 in. by 4 in., and two longitudinal walings (11 in. by 4 in.) are bolted to the top of the piles. The width of the groynes is 25 ft. 8 in. at the shore end and 10 ft. at the outer end. This type of groyne is really not at all suitable for the East Coast, its chief defects being: (1) It is too high, with the result that the foreshore is built up to windward and depleted to leeward. (2) To be effective it needs to be carried much further seaward. (3) It is altogether too expensive, both to erect and maintain; four ordinary low groynes might easily be constructed for the cost of one of these. (4) Groynes of this type are only breakwaters. The full force of the waves strikes them, stripping planks off during every heavy sea; at such times tons of chalk filling are washed out. During one gale twenty planks have been stripped off one of the groynes at Bridlington, and about 30 tons of chalk filling washed out. They were apparently intended more to break the force of the waves than that they should serve in collecting sand or beach on the foreshore. The higher a groyne is constructed above sand-level the less prospect there is of any accretion of beach on both sides.

The north foreshore at Bridlington extends about 130 yards to low-water mark of ordinary tides, and about 200 yards to low-water mark of spring tides, at an average



[*Spurr & Son, Photographers, Bridlington.*

FIG. 101.—LOW TIMBER GROYNES AT BRIDLINGTON.

slope of about 1 in 40. Since the erection of the sea-walls described in a previous chapter the scour upon the shore has greatly increased; and until a number of long, low timber groynes were erected, the sand was diminishing to a serious extent, and the foundations of some of the sea-walls were rapidly becoming quite bare. A system of groynes intended to prevent this scour, and retain the sand, was therefore devised. One of these is illustrated in fig. 101, and details are given in figs. 102 and 103. They somewhat resemble, above sand-level, the Case groynes; below sand-level, however, they differ altogether from that system.

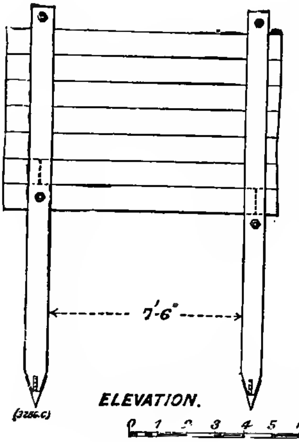


Fig. 102.

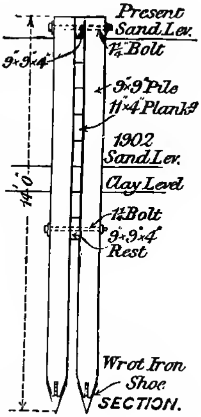


Fig. 103.

Bridlington foreshore consists of sand overlying boulder-clay. This clay is difficult to excavate, and if excavated, no matter how well it is filled in again, the sea will continually scour out the clay filling; the Case system of excavating for the concrete foundation of the uprights, shown in figs. 104 and 105, would therefore have been quite unsuitable. Originally it was recommended that the new timber groynes should extend seaward 300 ft. from the sea-walls; but this distance was subsequently reduced to 200 ft., in order to avoid inconvenience to persons driving on the sands, as low-water mark of ordinary tides is only 390 ft. from the sea-walls. The construction adopted was as follows:—Pitch-pine piles, shod with 18-lb. wrought-iron pile-shoes, were driven

FIG. 104.

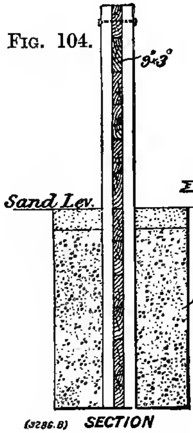
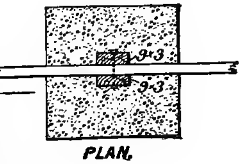


FIG. 105.

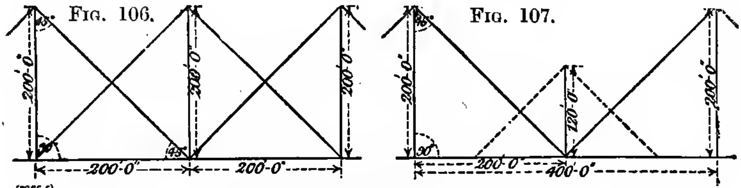


8 ft. into the boulder-clay in pairs, pitched at 7-ft. 6-in. centres. Pitch-pine planking, 11 in. by 4 in., was inserted between the piles, the bottom plank being fixed entirely in the clay. At every alternate set of piles a bearer was bolted on for the bottom plank to rest on; at the intermediate sets of piles the bottom plank itself was bolted to the piles instead of resting on a bearer, the object being to save excavation around the piles as much as possible, so that their stability should not be impaired. The groynes are so arranged that a depth not exceeding two planks usually projects above the sand-level; as the sand

accumulates, which it does most rapidly when the wind is blowing off-shore, additional planks are added. The planks are so arranged that one spans two bays, and the next three bays, and they are inserted so as to break joint.

One of the great advantages of this type of groyne is that the sand accumulates uniformly on both the windward and lee sides, and is arrested without impeding the flow of the sea. The timber was all creosoted, and the groynes were constructed at an angle of 10 deg. from the sea-wall in a southerly direction, as the greatest scour upon the shore takes place in a south-easterly or on-shore gale. The groynes in general were placed at a distance apart not exceeding their length. Some were shorter than others, the object of this being to catch the sand which escaped around the ends of the longer, by the projection of the shorter groynes. This is illustrated in figs. 106 and 107, where it will be seen that they are set out to form a series of equilateral triangles. The first four new groynes cost £718, or 18s. per lineal foot, and most of the others 12s. 3d. per lineal foot, but the latter was an exceptionally low tender. A few years ago builders and others were allowed to take sand from the north foreshore, and about 8000 tons were removed annually in this way. This

Fig. 106. Fig. 107.



SERIES OF EQUILATERAL TRIANGLES.

Scale of Feet.

unsatisfactory practice has now been stopped by the Town Council. At the present time there is probably 2,000,000 tons more sand upon the north foreshore than before the erection of the seventeen groynes just described, the beach level having been raised, as shown in fig. 103.

An inexpensive type of low timber groyne, erected by a landowner on the south foreshore of Bridlington, consists of a single row of 9-in. by 9-in. piles, driven at about 7-ft. centres. To secure the planking to them, a 9-in. by 4-in. upright is spiked to the pile above the clay-level. This vertical plank is blocked out 3 in. to form a space for the 9-in. by 3-in. horizontal planking to drop into.

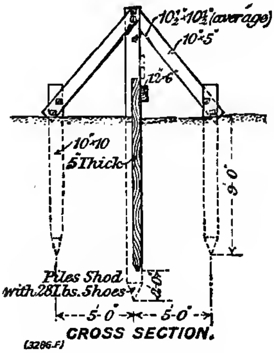


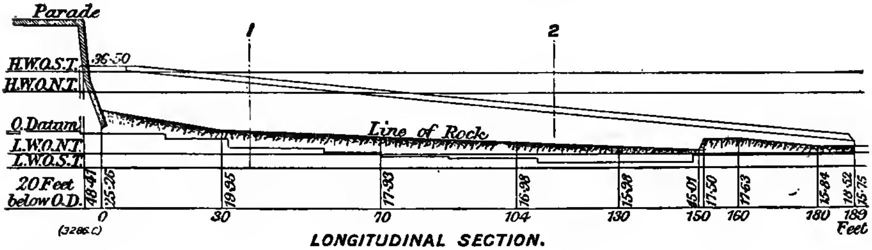
FIG. 108.

At Hornsea three timber groynes have been erected upon the foreshore. They are 745 ft., 430 ft., and 400 ft. in length respectively, and have had the desired effect of accumulating a large quantity of beach material; only exceptional tides are now able to reach the sea-wall. They consist, as shown in fig. 108, of 10½-in. by 10½-in. piles, and sheet-piling driven from 8 ft. to 12 ft., and carried to an average height of 2 ft. or 3 ft. above the foreshore; the sheeting is 5 in. in thickness, and above it 9-in. by 3-in. planking is added. Land-ties are inserted at intervals; they are 10 in. by 5 in., secured at their lower ends to 10-in. by 10-in. piles, which are driven 9 ft. into the foreshore. The distance between the centre of the main and toe piles is 5 ft.

The Worthing Corporation, in carrying out sea-defence works during the past sixteen years, have constructed a considerable number of timber groynes at a south-easterly angle of about 62½ deg. with the line of foreshore. Groynes at this angle were constructed some nineteen years ago in the adjoining parish of Lancing, from the designs of Mr R. F. Grantham, M.Inst.C.E., and the system had been followed at Worthing. They are 300 ft. long and from 300 ft. to 350 ft. apart, the angle at which they are constructed being practically at right angles to the prevailing south-west winds. One or two groynes have been constructed to a length of 400 ft. By this method it is found that the shingle is more evenly distributed on each side of the groyne. With the groynes at an angle, the ridge of the shingle at high-water mark is left with a pleasing curve, whereas in the old groynes it was generally a straight line extending at an angle from the windward side of one groyne to the leeward side of the adjoining groyne to the west. These groynes have been found to be of great advantage in the case of a gale from due south. Right-angled groynes (which run due south at Worthing) offer little resistance to the incoming waves, and the result is generally that the full force of the water is felt, causing a considerable scour and loss of shingle. When first constructed, a scour took place in some cases about midway between the groynes, until the shingle had sufficiently accumulated; where this had taken place a faggot breastwork was put in, which was sometimes buried with shingle in one tide. Loppings, from suitable trees planted in the streets of the town, have also been used very successfully for this purpose. Four groynes, constructed at the angle above named in April 1911, caused an accumulation of shingle of over 6 ft. in depth in six months, several piles and ties at the land end of the groynes being completely buried.

CONCRETE AND OTHER GROYNES.

Concrete-Block Groynes.—Where a foreshore is steep, and underlying the beach there is a rocky bed, as is, for instance, shown in fig. 112, concrete-block groynes, although somewhat expensive, may, with great advantage, be constructed. These may extend to low-water of neap tides or low-water of spring tides—the latter being preferable. The height above the foreshore to which such a groyne should rise will depend upon local circumstances, as will also the decision of the point whether the groyne should act also as a breakwater. No fixed rule as to the height can be given; but it may be stated that if the groyne extends seawards beyond low-water of neap tides, it should not in that length be of a greater height above the beach than 3 ft.—2 ft. would be preferable. An excellent example of a groyne of this type is shown in figs. 109 to 111, which represent one of a number of such groynes erected at Hastings by Mr Philip H. Palmer. Groynes of this class cost practically nothing to maintain. For long periods no damage has been sustained by concrete groynes of this type at Hastings, whereas considerable havoc was wrought from time to time during the same period to the high timber groynes. In a typical instance at Hastings, the foundations are carried down, as will be seen by the cross-sections, figs. 110 and 111, 4 ft. or more into the rocky bed of the foreshore. The groyne is 6 ft. in width at the base and 4 ft. at the top. These groynes have a ʌ-shaped top, which has, among others, the advantage of preventing children from running along the groyne, a practice more or less dangerous. The sides of the groyne are battered 1 in 10, and the structure is faced with concrete blocks, which again are faced with basalt. The blocks break joint. The longitudinal gradient of the groyne is 1 in 10, and the maxi-



LONGITUDINAL SECTION.

Fig. 109.

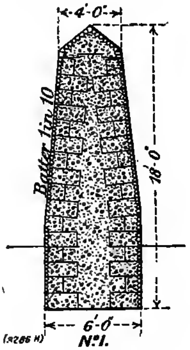


Fig. 110.

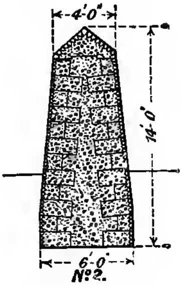


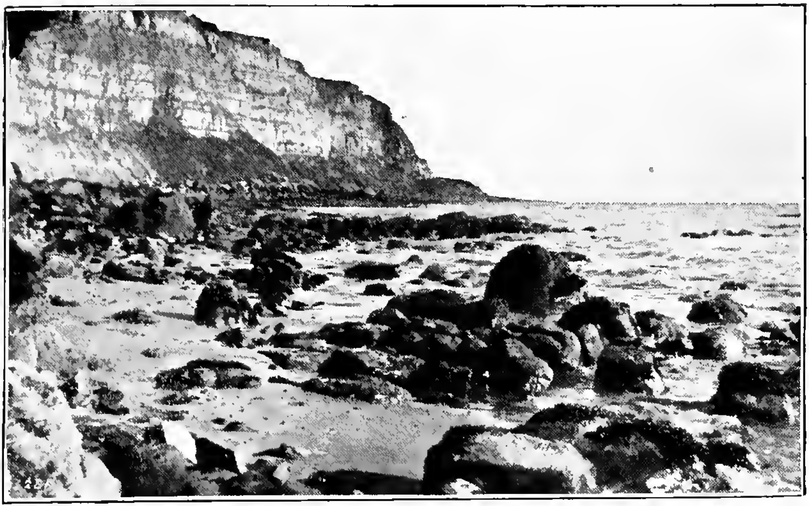
Fig. 111.

mum height above the bed-rock of the foreshore is 14 ft. The centre of the groyne is filled in with 6 to 1 mass concrete. Though this type of groyne has answered its purpose admirably at Hastings, and can be recommended for foreshores of a similar character, its cost prohibits its general use. The cost of the one illustrated and just described was £510. This, and most of the new groynes at Hastings, have been erected, very wisely, with an inclination towards the direction of the most destructive seas, which occur when a south-westerly gale blows at the time of spring tides.

If erected on some parts of our coast, a groyne similar to that described might be built of a somewhat lighter section; those built at Hastings, however, have to withstand a 25 ft. range of tide, and are none too heavy.

The Owens-Case Reinforced-Concrete Groyne.—The disadvantage of using timber in the construction of groynes is that the material is not durable. To overcome this difficulty the Owens-Case groyne has been introduced, which consists of a low groyne somewhat similar to that illustrated in figs. 101 and 102, the piles and planking being, however, of reinforced concrete. The following advantages are claimed for this construction: (1) It is durable and not liable to decay or attack by the shipworm; (2) capable of being quickly erected, either on the dry shore or in shallow water below low-water mark; (3) capable of being easily raised as accumulation takes place; (4) self-adjusting to the bottom in case of under-runs.

Reinforced-concrete piles of I section are driven or otherwise fixed in the foreshore, and slabs of reinforced



[*Forster, Photographer, Hastings.*

FIG. 112.—SHORE AT HASTINGS SUITABLE FOR CONCRETE GROYNES.

concrete are fitted in the spaces between them, sliding down into the grooves. The piles can be set in concrete or driven with a pile-driver or water-jet, the adoption of one of these alternate methods depending upon the nature of the shore. These groynes are not easily worn away by the attrition of pebbles, or damaged by floating objects colliding with them. They can be erected economically on a foreshore where shingle is plentiful for making the concrete. In constructing groynes of this type great care has to be exercised in the driving of the piles. Unless they are driven in precisely their right position there will be difficulty in getting the reinforced-concrete slabs to fit into the rebates of the piles. Dr Owens also recommends a reinforced-concrete groyne similar to the timber groyne shown in fig. 108, but constructed as shown in fig. 113.

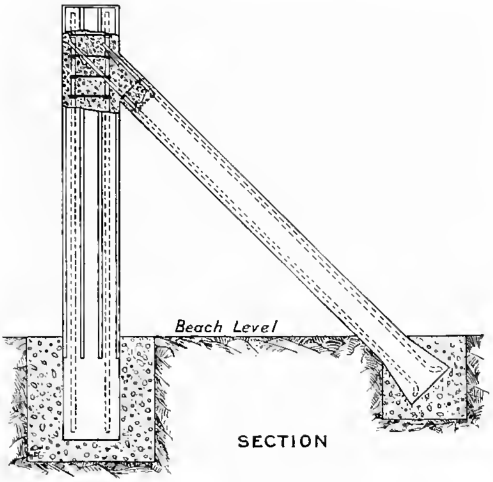


Fig. 113.—Owens-Case Improved Type of Groyne.

Chain-Cable Groynes.—These are the invention of

Mr Allanson-Winn, and their object is to arrest the material travelling along the coast below low-water mark. They have in a number of instances proved most successful. They consist of a heavy chain cable, to which is attached trees, bushes, or any other material which is likely to offer resistance to the passing of drifting seaweed and detritus. The trees, etc., in time become embedded in the drifting material, and the groyne becomes silted up. Economy can undoubtedly be claimed for this type of groyne, which can be erected in a few tides. Its unsightly appearance prohibits its use on the foreshore in front of a town. In addition to the above advantages claimed for it, it can easily be removed if necessary, and sold at approximately the original cost. The total cost of these groynes is about one-fifth of that of the cheapest timber groyne yet devised. It is immune from the attacks of the ship-worm, and is exceedingly cheap as regards maintenance. The flexible chain accommodates itself to the inequalities of the sea-bed or shore surface.

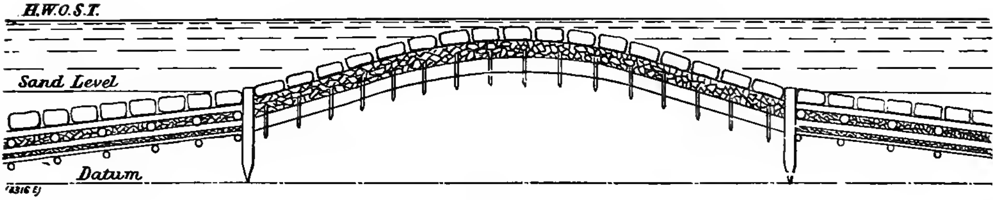


Fig. 114.

Groyne at Ostend.—A novel type of groyne may be seen at Ostend, and should be briefly referred to; it consists of pitching constructed in the form of an arch (see fig. 114). These groynes are 30 ft. wide, the sides being protected by fascine work to a width of about 13 ft.

This is fastened down by stakes. The groynes extend seawards from 150 to 200 yards, and one of the principal advantages claimed for them is that they do not stand up above the shore so prominently as does the ordinary type. A right-angled obstruction to the shore is therefore avoided. The rounded top of the Ostend groyne prevents scour; but, while admitting that advantage, it must be pointed out that the groyne is expensive to construct and to maintain, and has the disadvantage of taking up a large amount of valuable space on the foreshore. On that account principally, it would be unsuitable for adoption on our coasts.

CHAPTER XI.

DESIGN OF SEA-WALLS. EROSION *VERSUS* ACCRETION. CONCRETE FOUNDATIONS.

WHERE the excavation for foundations is into boulder-clay, as at Bridlington, and the beach is covered by the sea at every tide, the author recommends the following method of putting in the concrete foundations:—

A short length of 20 ft. or so having been opened out to the required depth of 10 ft. to 15 ft., and of the required width of, say, 15 ft. 6 in. (see figs. 115 and 116), a sump should be dug at one end. This may be sunk 4 ft. below the bottom of the trench, and should be 4 ft. by 4 ft. A narrow trench should then be cut along the centre of the section excavated, and a 9-in. sanitary pipe drain laid leading to the sump. The concrete should then be filled in, a key being made between successive lengths of con-

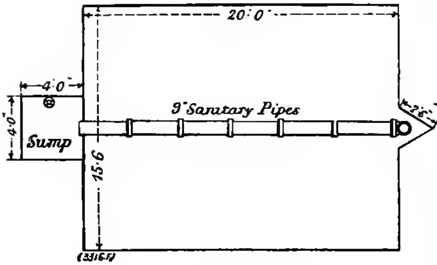


FIG. 115.

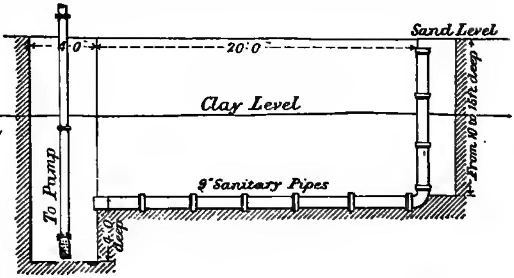


FIG. 116.

crete, this key (V-shaped) being 2 ft. 6 in. by 2 ft. 6 in. (see fig. 115). When the next section is excavated the drain-pipe must be continued with a slight fall towards the sump until the whole of the foundations have been put in. The water may be pumped out and discharged at a distance. Where the foundations of a sea-wall are directly on to the solid rock, as frequently happens, the rock may be cut away for a depth of about 9 in., and then building may proceed on it direct; there is no need in such a case for the foundations to be widened out, as on any other natural foundation.

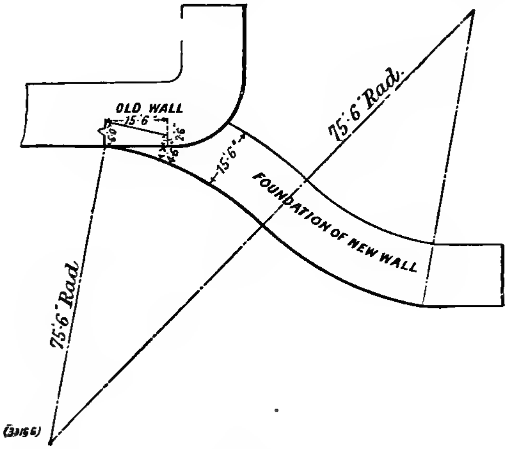


Fig. 117.

Where a new sea-wall is to be built seawards, but in continuation of an old wall, and the two walls have to be joined, it is of the greatest importance that a good connection should be made between the foundations of the old and the new work. A typical method of accomplishing this is shown in fig. 117, which represents the foundations of the old Prince's Parade wall at Bridlington, and the northward and seawards extension of that wall.

STRENGTH OF SEA-WALLS.

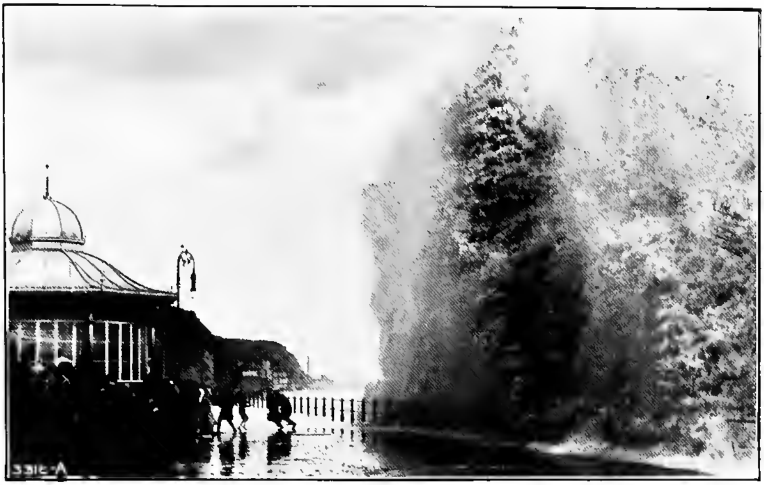
It is impossible to calculate with any degree of accuracy the forces which act upon a sea-wall. The force exerted and the vibration of the structure produced by a wave striking a wall are indefinite quantities. In designing sea-walls in positions where wave-action will play on the wall at high-water of ordinary spring tides, and where the latter rise several feet up the wall, the following simple formula may be adopted :—

$$\frac{H}{2} = \text{thickness of wall at base.}$$

The foundations should extend beyond this width, but the thickness of the wall immediately above them may be equal to half the height of the wall. A number of walls have been constructed to this formula, with satisfactory results.

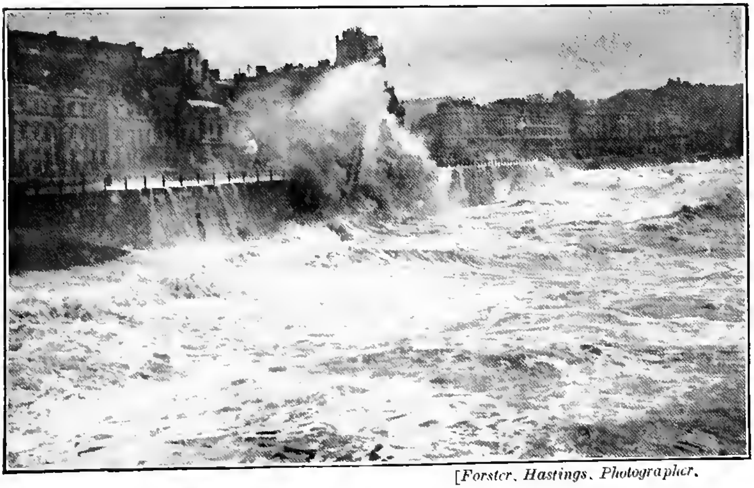
DESIGN OF WALL TO PREVENT FLOODING.

Where a town is to be protected by a low sea-wall, and the town itself lies at a lower level than the proposed promenade at the back of the wall, it is very necessary, if flooding is to be prevented, that (*a*) the sea-wall be carried as far seawards as possible, so as to give considerable width to the sea-front; (*b*) the wall must be so designed that provision is made for throwing the waves back; (*c*) it must not be too low, abnormal tides which may rise from 4 ft. to 6 ft. above high-water of ordinary spring tides, being taken into consideration; (*d*) the town must be further protected by the erection on the land side of the promenade of a dwarf wall—say, 2 ft. to 3 ft.



[*W. J. Willmet, Hastings, Photographer.*

FIG. 118. WAVE BREAKING ON HASTINGS PROMENADE DURING ON-SHORE GALE.



[*Forster, Hastings, Photographer.*

FIG. 119.—WAVE BREAKING ON HASTINGS PROMENADE DURING ON-SHORE GALE.

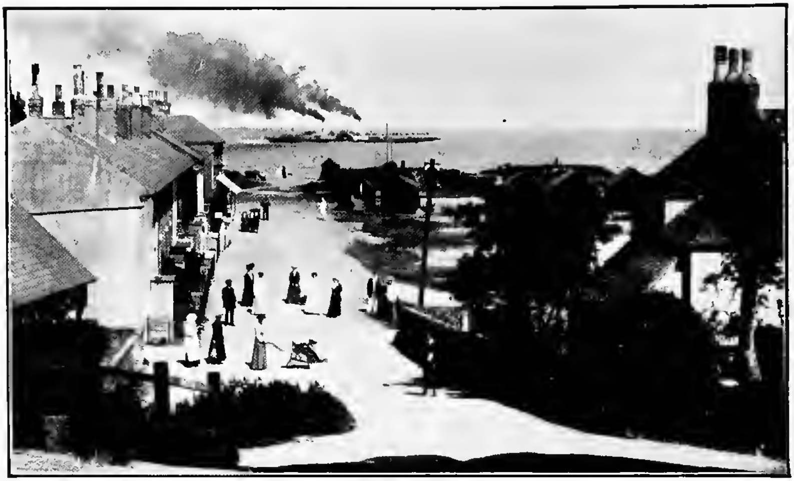
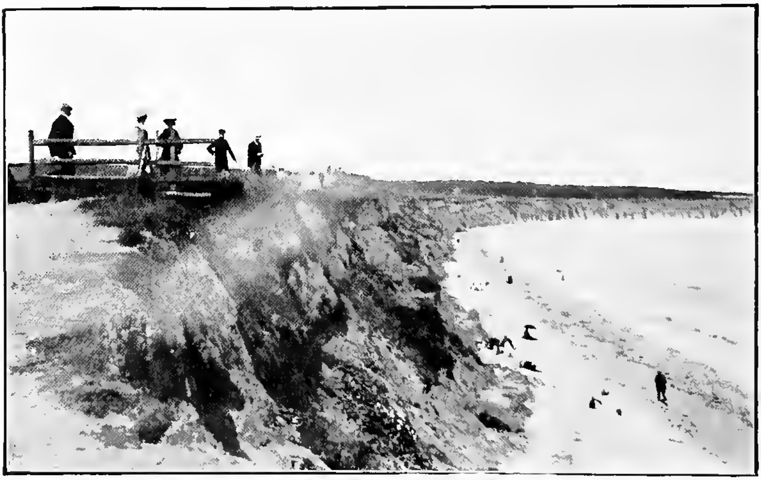


FIG. 120.—RECLAIMED LAND, KINGSDOWN, NEAR DEAL.



[*Spurr & Son, Bridlington, Photographers.*

FIG. 121.—EROSION AT SEWERBY CLIFFS, BRIDLINGTON.

high—so that when a wave strikes the sea-wall and rises, and the wind blows much of it over on to the promenade, it shall be unable to travel far, its course being impeded by this dwarf wall. The manner in which the waves break over a sea-wall during an on-shore gale and fall on to the promenade is shown in figs. 118 and 119. These views represent waves breaking during a south-westerly gale at Hastings.

Erosion *versus* **Accretion.**—The total area of England in 1867, excluding the area of the foreshore and that covered by the tides, according to information issued by the Board of Agriculture, was 32,590,397 acres. In 1900, or thirty-three years later, it had diminished to 32,549,019 acres, or a reduction in area of 41,378 acres, and this after taking into consideration the land gained by accretion. Assuming the average value per acre of the lost land to have been £20, this means a loss of £827,560. While this loss has been proceeding for centuries, the value per acre of the land eroded increases year by year, for the population of England is increasing, while its area is annually decreasing. The whole matter is therefore a national one, and should interest the inland owner quite as much as the man whose land abuts upon the coast. Fig. 120 illustrates a part of the coast where accretion has been going on for centuries. It is a view taken at Kingsdown, near Deal. In that case the chalk cliffs, at the foot of which the waves of the sea used to break, are now nearly a quarter of a mile inland, and between them and the sea a village has sprung up, as seen in the illustration.

On the other hand, fig. 121 represents a part of the coast immediately north of Bridlington where the coast-line does not remain the same for two consecutive days, owing to the erosion.

Geologists are fairly well agreed that after this country was heaved up out of the sea on the last occasion, the land level was much higher than it is to-day. Evidence of this may be found in the various submerged forests around our coasts ; a tree from one of these at Hastings was shown in fig. 23. Raised beaches are also met with here and there, an interesting one having been discovered a few years ago in the Sewerby cliffs at Bridlington. Although it is difficult to prove it, the land is gradually sinking, as is also the bed of the ocean. The subsidence, however, is so slow that it cannot be measured.

CHAPTER XII.

MATERIALS AND METHODS OF PRESERVATION OF SEA-WORKS.

THE chief consideration in selecting materials for use in coast-protection works is that of durability, having at the same time regard, of course, as to the cost. A sea-wall, for example, faced with granite or basalt rock would last longer than one built of concrete *in situ*, and would cost less in repairs; but the initial cost in most cases would prohibit the use of either of the two former materials.

It is now intended to give some information regarding the use of those materials which are most commonly used in the construction of sea-defence works, such as Stone, Concrete, and Timber, and to include notes on the use of Reinforced Concrete—a material which in the future will be considerably used in such work. The method of preservation will then be dealt with.

STONE.

Basalt.—Basalt is undoubtedly the best stone with which to face a sea-wall or breakwater; this is a very hard rock of high specific gravity, which is one of its chief advantages, it is extremely durable, and is a columnar rock, hexagonal in shape, which renders it easy to key. It has been used largely in Holland, and examples of its use in this country may be seen, among other places, at Blackpool and Hastings. A good example of its use in the construction of harbour piers may be found at Hull.

The weight per cubic foot of this material is about 180 to 185 lb.

Granite.—There are various kinds of granite, and these vary in specific gravity, they vary also in colour, some being grey, others red. When fractured they should present a bright appearance.

The material is suitable for facing sea-walls and harbour walls, but the cost, like that of basalt, renders it little used for the former purpose.

The granites vary in weight from 165 to 185 lb. per cubic foot as follows:—

	Weight per Cubic Foot in lbs.
Peterhead (red granite)	165
Aberdeen (grey granite)	165
Cornish	166
Guernsey	184

Sandstone.—This is largely used in maritime work. The author has used it for this purpose very extensively, and he recommends Bramley Fall, Caithness, and Whitby sandstones as being the most durable for sea-work. The weight per cubic foot of these stones respectively is 156, 165, and 160 lb. The sea-walls at Bridlington are faced with Bramley Fall stone, which costs, delivered at Bridlington Station from the quarries near Leeds, 6s. 10d.

per cubic yard dressed ready for use; these stones varied in size as explained in an earlier chapter, and this price refers to the " new " sea-walls.

One of the sea-walls at Bridlington was built forty years ago, and most of the Bramley Fall stone-facing in this wall is in an excellent condition. Not one penny has been spent in replacing any of the stones. Caithness stone is even more durable, and has been used very considerably, and the author recommends its use; while the harbour pier (North Pier) at Bridlington was built with Whitby stone seventy years ago, and this is in a splendid condition.

Derby-grit sandstone has also been used for sea-works.

Limestone.—The author does not recommend the use of limestone, if sandstone can be obtained at a reasonable rate, although some of the harder rocks have been used in harbour and breakwater construction.

Quartzite.—Quartzite is a very useful stone to use in maritime works, and it has been used very extensively for this purpose. " The Holyhead breakwater is almost entirely constructed of it." [1]

Chalk.—Chalk stones should never be used in the construction of sea-walls, either as plums in the aggregate in a mass-concrete wall, or for facing purposes. It breaks up when subject to frost and when becoming alternately wet and dry, and the action of sea water on it causes it to become soft; it is quite unsuitable.

---

[1] *Harbour Construction*, by William Shield, F.R.S.E. (Longmans, Green & Co.).

CONCRETE.

No material has been so extensively used in building sea-walls as this: it will probably always take the premier place in this respect. The foundations and backing of sea-walls are almost always of concrete, often the wall is formed throughout of mass-concrete, and frequently it has concrete foundations and backing, and a concrete-block face. In either of these cases concrete predominates. The quality, however, of this material is of the utmost importance.

Proportions.—The proportions to use in foundations and backing may be 1 : 2 : 6 (one cement, two sand, six shingle); the author uses 1 : 2 : 4, and recommends this, and in concrete blocks 1 : 2 : 2. In a mass-concrete wall the 6 in. of concrete at the face of the wall should certainly be of 1 : 2 : 4 concrete, some engineers prefer 1 : 2 : 2, and this should be a finer mixture.

Cement (*Tensile strength*).—Only the best Portland cement should be used, and this should meet the requirements of the "1910 Amended British Standard Specification for Portland Cement," or those of the "American Society for Testing Materials."

As to the former, this specifies that the average breaking stress of briquettes made of neat Portland cement shall be as follows:—

At seven days after gauging—not less than 400 lb. per sq. in. of section.

At twenty-eight days the briquettes must show an increase on the breaking stress at seven days after gauging of not less than:—

25 per cent. when the seven-day test is above 400 lb. and not above 450 lb.
20 per cent. when the seven-day test is above 450 lb. and not above 500 lb.
15 per cent. when the seven-day test is above 500 lb. and not above 550 lb.
10 per cent. when the seven-day test is above 550 lb. and not above 600 lb.
5 per cent. when the seven-day test is above 600 lb.

The test for tensile strength (cement and sand, 3 to 1) is specified to be not less than :—

Seven days' test.	*Twenty-eight days' test.*
150 lb. per sq. in. of section.	250 lb. per sq. in. of section.

The American Standard Specification for cement requires a higher tensile strength, which is as follows :—

NEAT CEMENT.

Age.	Strength.
24 hours in moist air	150–200 lb.
7 days (1 day in moist air, 6 days in water)	450–550 ,,
28 days (1 day in moist air, 27 days in water)	550–650 ,,
One part cement, three parts sand.	
7 days (1 day in moist air, 6 days in water)	150–200 ,,
28 days (1 day in moist air, 27 days in water)	200–300 ,,

Aggregate.—The choice of this is a very important matter. It may consist of any hard stone, preferably broken stone, such as granite or other rock, or of shingle.

In mass-concrete walls, a few plums might be allowed, but the author does not favour these.

Limestone should not be used, and the aggregate should vary in size from ¼ in. to 2 in.

Sand.—Sea-sand will be used, and it is most necessary that this shall be clean.

Mixing.—This may be done by hand, or by machine, the latter is certainly preferable.

Water.—Fresh water should be used where possible.

Crushing Strength.—There should certainly have been included in the British Standard Specification some clauses dealing with the compressive strength of concrete, for foundations are often subject to severe compression. "The recommendations of the Royal Institute of British Architects' Joint Committee are that the crushing strength of concrete of a mixture of 1 : 2 : 4 (cement, sand, and hard stone) should be not less than 2400 lb. to 3000 lb. per sq. in. after twenty-eight days."[1]

Consistency.—Generally speaking, a "plastic" mixture should be used.

Laying.—It is of the greatest importance that the concrete should not be thrown into the trench from a staging at some height above, but shoots should be used. The concrete should be well punned, and great care taken in placing.

REINFORCED CONCRETE.

The aggregate in this case should not exceed 1 inch in size; it should vary from ¼ in. to 1 in. The reinforcement used may be one of the many patent systems now in the market, such as Expanded Metal, Indented Steel Bars, Kahn Trussed Bars, Lug Bars, etc., or may consist of plain steel rods, which method the author has adopted frequently. In any case, the property of the reinforcing steel should be as follows :—

---

[1] *Reinforced-Concrete Construction*, by Adams and Matthews (Longmans, Green & Co.).

" Its ultimate strength should not be less than 60,000 lb. per sq. in.

" Elastic limit 50 to 60 per cent. of the ultimate strength.

" Modulus of elasticity, 30,000,000 lb. per sq. in.

" Working stress, factor of 4 } according to the nature
,, ,, 5 } of the structure.

" The steel should afford an elongation of not less than 22 per cent. in round bars less than one inch in diameter, on a gauge length of 8 diameters, and should stand bending cold 180 degrees to a diameter of the thickness of the pieces tested without fracture on the outside of the bent portion. All rods, plates, bars, and other reinforcement should be of mild steel, manufactured on the open-hearth, basic or acid Siemens process." [1]

PRESERVATION OF SEA-WALLS.

Stone-Faced Walls.—These seldom require repairs, although often the stones become pitted by the force with which the shingle is hurled against the wall during a storm (a good example of this may be seen at the western arm of the Dover harbour), but occasionally one of the stones may wear somewhat rapidly ; in this case it will either be necessary to cut out the whole stone and replace it with a sound one, or if the defect only extends

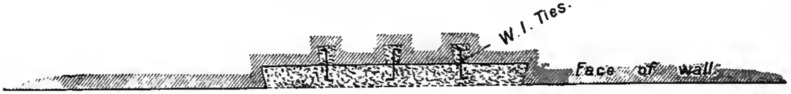
[1] *Reinforced-Concrete Construction*, by Adams and Matthews (Longmans, Green & Co.).

to a part of the stone, and the latter is a large one, the defective part only need be cut out and replaced. Basalt and granite facing will require no repairs.

Concrete-Block Facing.—A heavy sea will occasionally result in the tearing out of the face of some of the blocks in a concrete-block faced wall; when this happens the damaged blocks must be cut out and replaced in the manner described for stone-faced walls.

Mass-Concrete Walls: Surface Repairs.—Mass-concrete walls require more repairs than any other type.

The face not only in time becomes pitted, but pieces of the concrete facing are often broken off by the shingle striking the wall, the frost then gets into the concrete, and the wall requires immediate repair in order to prevent the damage extending.



Scale: 1 inch = 3 feet.

FIG. 122.

The author has had much experience in repairing walls of this type, and he recommends the following treatment:—

Cut away the damaged portion of the wall to a depth of, say, 3 or 4 in. over the affected area, leaving the surface at the back rough, so that the new concrete will get a key. Cut holes in the wall about 2 in. square and 3 in. deep, and into these fix wrought-iron ties of the shape shown in fig. 122, set these in neat cement in the proportion of one per square foot of area of wall, and when well set apply the new concrete (sand, and very fine sea gravel, and cement), 2 : 1 : 1. The edges of the cutting must be splayed as shown in the illustration. This makes a permanent and satisfactory repair which will last for years.

Deep Cracks.—Walls of this type frequently exhibit cracks, and sometimes these are alarming. The best method of treating them is by the use of the Cement-Gun. By means of this ingenious appliance cement mortar is forced into the crack by compressed air. In America this apparatus has been much used, and in the building of the Panama Canal it proved a great success. The machine is an American device, and by means of it cement can be forced under pressure into cracks of almost any depth, the crack itself afterwards being pointed up with neat Portland cement if above the range of the tides, and if below, with Roman cement.

The surface also of a much pitted mass-concrete wall may be much improved by spraying it with the Cement-Gun. For further information regarding this appliance see *Concrete and Constructional Engineering* of May and October 1912.

Underpinning Walls.—The scour at the base of a wall is sometimes such as to require the wall to be underpinned.

The author has had to advise in several such cases, and what he recommends is as follows :—

Assuming the wall is resting upon a clay foundation, as shown in fig. 123, and that this clay has been scoured away until the sea is able to wash under the front portion of the foundations, sheet piles 7 in. by 3 in. should be driven about three feet seaward of the wall, and running parallel with the latter; these piles should be fairly long, say 12 to 14 ft., and after being driven, the sand at the back of same should be removed, the clay cut out as shown in fig. 123, so to form a key, and 4 to 1 Portland cement concrete filled in, and well covered up by iron plates or galvanised sheets well weighted down. In some cases it will be necessary to form a wider apron, with a toe-piece as shown in fig. 124; in this case it is very important that the toe-piece shall extend well down into the clay as shown.

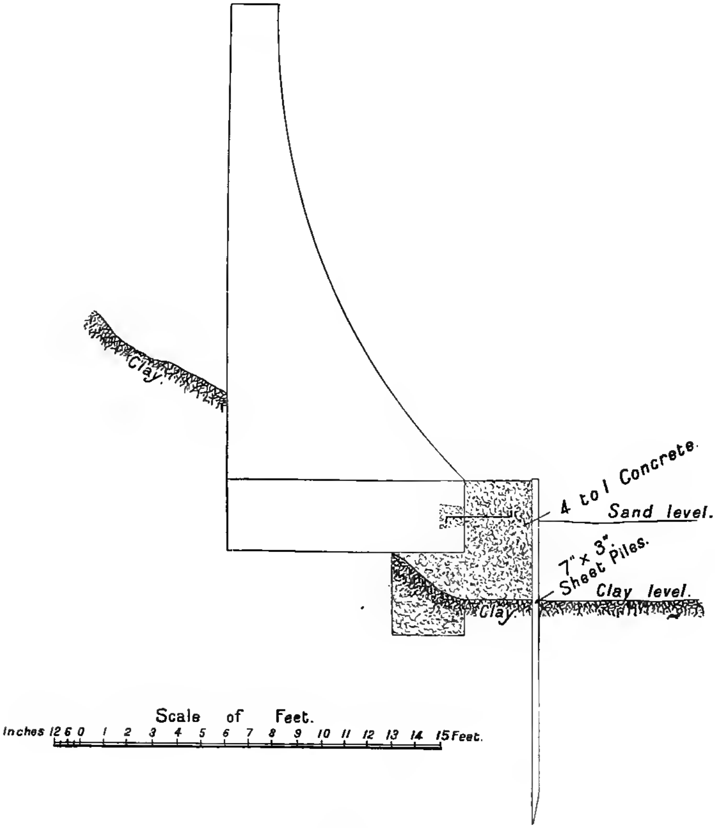


FIG. 123.

TIMBER.

Various kinds of timber are used in sea-works, but those principally in use are as follows :—

Pitch-pine.
Baltic redwood.
English and American oak.
Greenheart.
Jarrah.

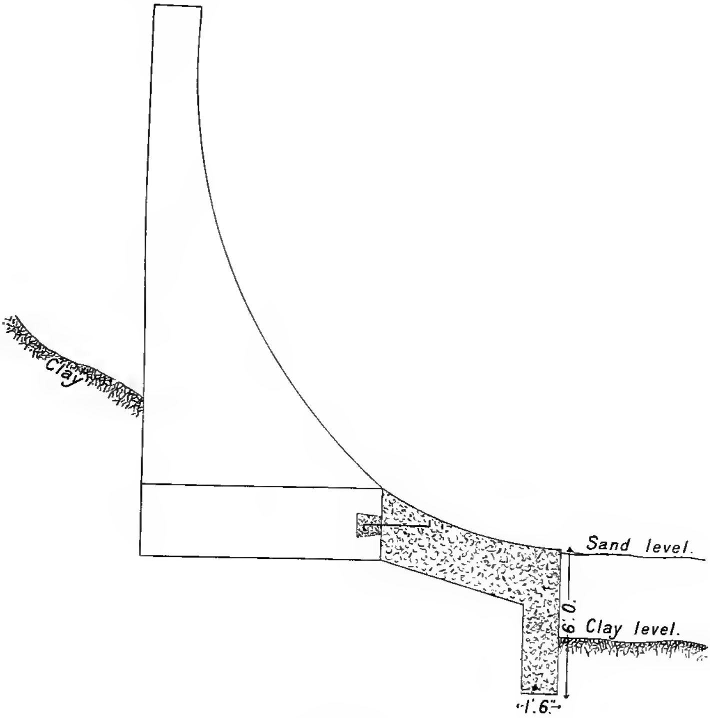


Fig. 124.

Pitch-pine.—Pitch-pine has been used more than any other timber, and it is extremely valuable for marine work, chiefly on account of its being procurable in large scantlings up to or even above 20 in. square, and of lengths up to 40 ft. This makes it of great use for piles, which it is possible to drive without splitting. For groynes the author uses no other timber, and for the construction of breakwaters and jetties it is invaluable and much less expensive than oak or teak.

Its defect is that it is easily attacked by the common ship-worm, *Teredo navalis*, and other marine animals. They get into the timber in a variety of ways, but chiefly at sawn ends, and through bolt-holes and joints. Some timbers, such as greenheart and jarrah, naturally resist sea-worms, they are repellent to these worms as they contain a poisonous oil which is distasteful to them; these timbers are therefore from this point of view admirable for sea-works, although there have been instances where even greenheart and jarrah have been badly attacked by worms. A temporary jetty of jarrah wood put down at Colombo by Sir Guilford Molesworth was honeycombed by the *Teredo* in less than two years.

The author finds that to creosote pitch-pine is a good preventative against attacks by sea-worms, and he specifies that no less than 8 lb. of creosote shall be injected per cubic foot of the timber; it is not always possible to get this quantity into pitch-pine, but 6 lb. can usually be forced in per cubic foot. 10 lb. can easily be injected into redwood, and some English engineers specify 12 lb., while French engineers occasionally specify as high as 18 lb.

Baltic Redwood.—This, although one of the cheapest materials to use for piles and other sea-works, is nevertheless one of the most useful if it is well creosoted. It can be obtained in 12- and 13-in. logs, up to 40 ft. in length. There is always plenty of it in the market, and it is a material which is easily worked. In spite of the creosote redwood occasionally is destroyed by sea-worms.

English and American Oak.—The cost of these usually prohibit their use; especially is this so with English oak, which is now very scarce; they are nevertheless admirable for piling and other marine work; they are not easily attacked by the worm; they last for many years, and like pitch-pine can be obtained in large logs of great length.

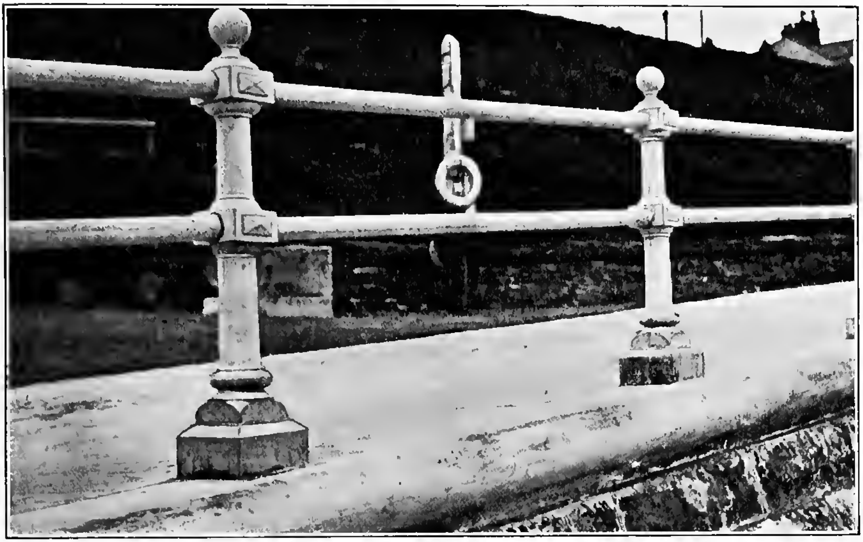
Greenheart.—This is almost an ideal timber to use for the purpose we are now discussing. It is naturally repellent to the worm; can be obtained in fairly large logs (up to 15 in.), and of great length (up to 40 ft.); it is most durable, and some of the finest timber work in connection with our harbours has been executed in greenheart. It would be more used were it not somewhat scarce and costly. Its defect is that it has a tendency to split.

Jarrah.—Jarrah from Western Australia is another timber which usually escapes the worm; it is tough and durable, and obtainable in logs of considerable size (up to 24 in.) and length (up to 50 ft.). Only the best jarrah should be used; there are several qualities, some of which are quite unsuitable for marine work. The chief disadvantage of using this material for piling is that it splits. The author has known as many as six wrought-iron straps necessary to be placed around a long jarrah-wood pile to ensure that it did not split.

Cleaning Piles.—In order to preserve the timber, it is well to periodically scrape piles that become covered with vegetation, and to clean off any shell fish that may have become attached to them.

Generally.—Owing to the fact that timber piles are liable to decay and to be attacked by sea-worms, the author recommends that in place of timber reinforced-concrete piles should be used whenever possible; the initial cost of this material often prohibits its use, but its permanence and low cost of maintenance should be carefully considered by the engineer when deciding in this matter. W.I. bolts in timber piling should be galvanised, this will preserve them considerably, otherwise they soon corrode.

Railings and Standards on Sea-Walls.—These may be constructed of various materials. The standards are usually of cast iron, but reinforced concrete has been used in one or two instances recently, and this material is undoubtedly very suitable for the purpose, for it possesses the quality of increasing in strength with age and of being moulded into any desired shape. Rails usually consist of wrought-iron tubes, say, 2½ inches in external diameter, and these with the cast-iron standards are painted with three coats of oxide-of-iron paint, or with "Ferrodor," or some other non-corrosive paint,—there are a number at present in the market. The author always specifies that the tubes shall be galvanised, and while the initial cost of this is slightly more than painting, the rails if galvanised last for many years without requiring one penny to be spent on them, and look cleaner and better. Cast-iron rails are sometimes used; the author has used them of rope pattern, and while they look very ornamental they are not suitable, for should the force of a wave strike them they break. They should also be painted at least every other year, but preferably annually, and should not be less than 2¾ in. in diameter,—3 in. would be better. A good illustration of reinforced-concrete standards and railings is shown in fig. 125, which represents the parapet railings recently fixed at the north end of Long Sands, Tynemouth. They were designed by the Borough Engineer of that town—Mr John F. Smillie—and look well; the reinforcement consists of ¼-inch steel rods. The author would prefer to use reinforced-concrete standards and galvanised wrought-iron rails.



[*Borough Engineer*, *Tynemouth.*

FIG. 125.—REINFORCED-CONCRETE RAILS AND STANDARDS AT TYNEMOUTH.

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